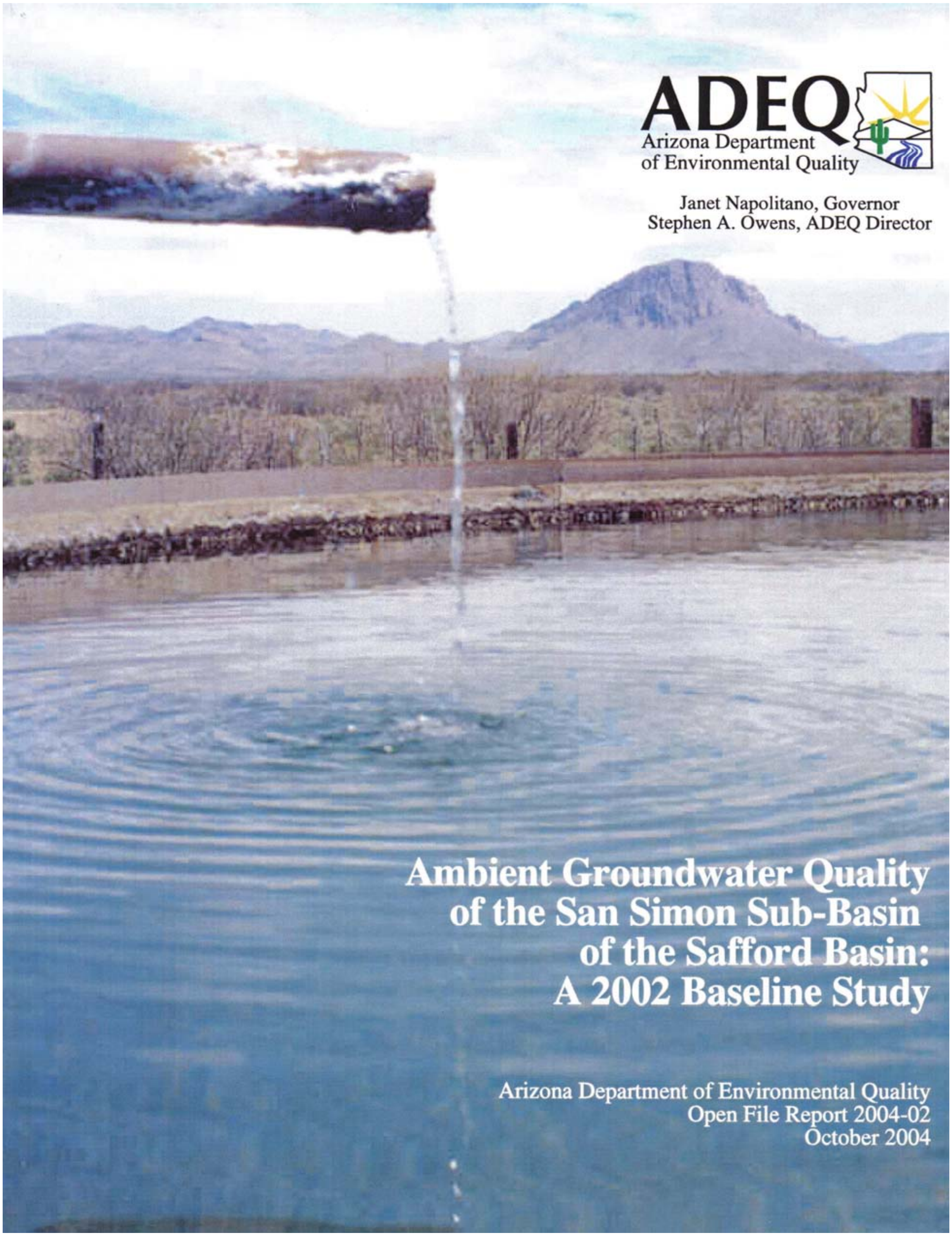

ADEQ
Arizona Department
of Environmental Quality

Janet Napolitano, Governor
Stephen A. Owens, ADEQ Director

Ambient Groundwater Quality of the San Simon Sub-Basin of the Safford Basin: A 2002 Baseline Study

Arizona Department of Environmental Quality
Open File Report 2004-02
October 2004

Ambient Groundwater Quality of the San Simon Sub-Basin of the Safford Basin: A 2002 Baseline Study

By Douglas C. Towne
Maps by Lisa Rowe

Arizona Department of Environmental Quality
Open File Report 2004-02

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Thanks:

Report Preparation:	Philip Amorosi, Nancy Carroli, Lorraine Cona, Maureen Freark, and Wang Yu
Field Assistance:	Elizabeth Boettcher, Don Hall, Joe Harmon, Cheri Horsley, Jason Mahalic, and Bob Wallin. Special recognition goes to the many well owners who were kind enough to give permission to collect groundwater data on their property.
ADEQ Management:	Linda Taunt - Manager, Hydrologic Support and Assessment Section Wang Yu - Supervisor, Groundwater Monitoring Unit
Photo Credits:	Douglas Towne

Report Cover: A stark contrast exists between a brimming stock tank supplied by groundwater from Little Artesian Well and the surrounding arid landscape of the San Simon sub-basin. As is characteristic with many wells in the area, artesian pressure has decreased and a windmill now assists the water in reaching the surface. Orange Butte, a noted landmark in the San Simon Valley, rises in the background to the east.

Other Publications of the ADEQ Ambient Groundwater Monitoring Program

ADEQ Ambient Groundwater Quality Open-File Reports (OFR):

Detrital Valley Basin	OFR 03-03, November 2003, 65 p.
San Rafael Basin	OFR 03-01, February 2003, 42 p.
Lower San Pedro Basin	OFR 02-01, July 2002, 74 p.
Willcox Basin	OFR 01-09, November 2001, 55 p.
Sacramento Valley Basin	OFR 01-04, June 2001, 77 p.
Upper Santa Cruz Basin	OFR 00-06, Sept. 2000, 55 p. (With the U.S. Geological Survey)
Prescott Active Management Area	OFR 00-01, May 2000, 77 p.
Upper San Pedro Basin	OFR 99-12, July 1999, 50 p. (With the U.S. Geological Survey)
Douglas Basin	OFR 99-11, June 1999, 155 p.
Virgin River Basin	OFR 99-04, March 1999, 98 p.
Yuma Basin	OFR 98-07, September, 1997, 121 p.

ADEQ Ambient Groundwater Quality Factsheets (FS):

San Simon Sub-basin	FS 04-06, October 2004, 4 p.
Detrital Valley Basin	FS 03-07, November 2003, 4 p.
San Rafael Basin	FS 03-03, February 2003, 4 p.
Lower San Pedro Basin	FS 02-09, August 2002, 4 p.
Willcox Basin	FS 01-13, October 2001, 4 p.
Sacramento Valley Basin	FS 01-10, June 2001, 4 p.
Yuma Basin	FS 01-03, April 2001, 4 p.
Virgin River Basin	FS 01-02, March 2001 4 p.
Prescott Active Management Area	FS 00-13, December 2000, 4 p.
Douglas Basin	FS 00-08, September 2000, 4 p.
Upper San Pedro Basin	FS 97-08, August 1997, 2 p. (With the U.S. Geological Survey)

ADEQ Targeted Groundwater Quality Open-File Reports (OFR) :

An Assessment of Methyl Tertiary-Butyl Ether (MTBE) Groundwater Occurrence in Maricopa County. ADEQ Open File Report 02-03, February 2003, 48 p.

The Impacts of Septic Systems on Water Quality of Shallow Perched Aquifers: A Case Study of Fort Valley, Arizona. ADEQ Open File Report 97-7, February 1997, 70 p.

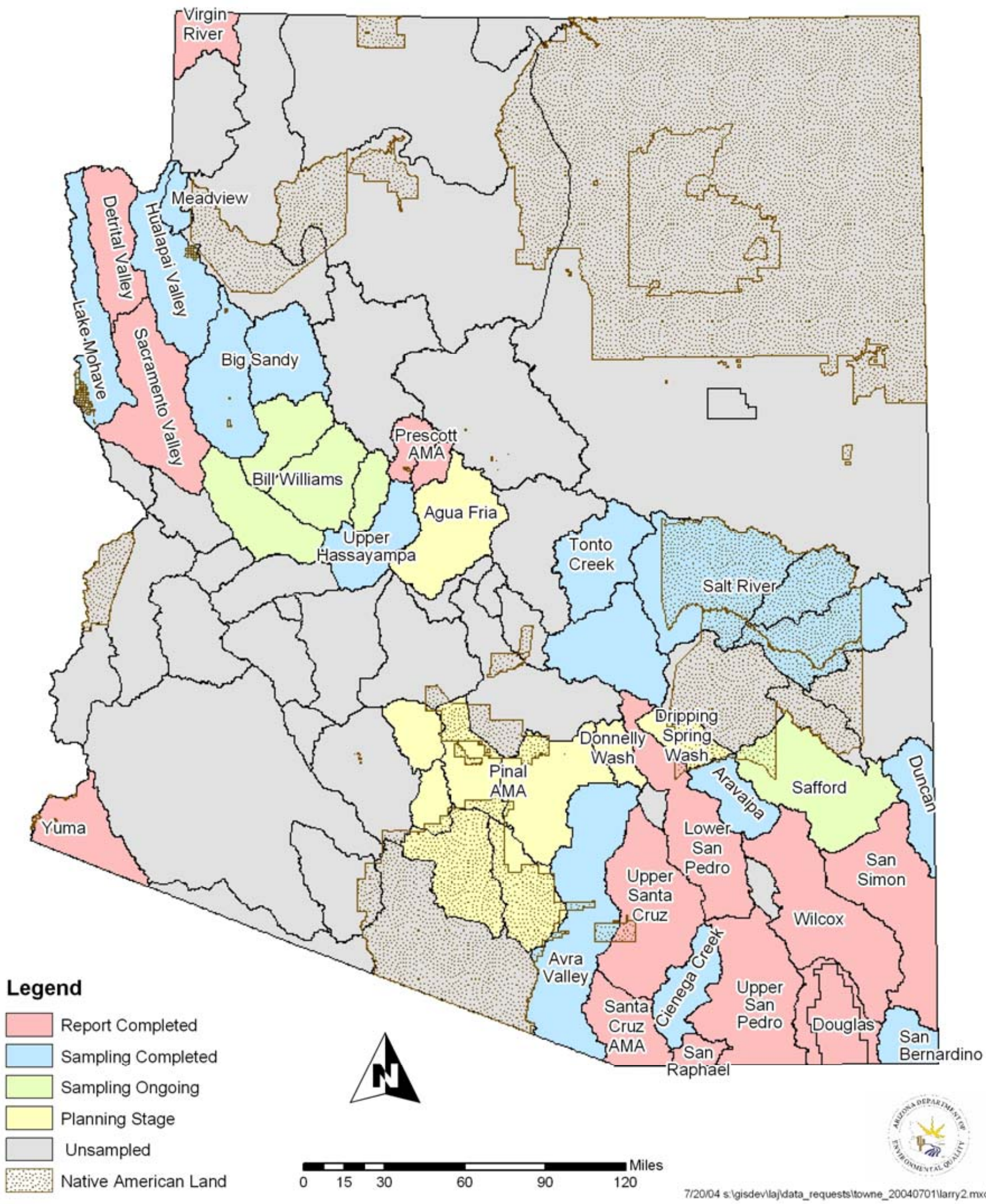
Most of these publications are available on-line.
Visit the ADEQ Ambient Groundwater Monitoring Program at:

http://www.azdeq.gov/environ/water/assessment/ambientst.html

http://www.azdeq.gov/environ/water/assessment/targeted.html

Status of GW Basins in the Ambient Monitoring Program

July 2004



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ABBREVIATIONS

amsl	above mean sea level
af	acre-feet
af/yr	acre-feet per year
ADEQ	Arizona Department of Environmental Quality
ADHS	Arizona Department of Health Services
ADWR	Arizona Department of Water Resources
ARRA	Arizona Radiation Regulatory Agency
AZGS	Arizona Geological Survey
As	arsenic
bls	below land surface
BLM	U.S. Department of the Interior Bureau of Land Management
°C	degrees Celsius
$CI_{0.95}$	95 percent Confidence Interval
Cl	chloride
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
gpm	gallons per minute
GWPL	Groundwater Protection List pesticide
HCl	hydrochloric acid
LLD	Lower Limit of Detection
Mn	manganese
MCL	Maximum Contaminant Level
ml	milliliter
msl	mean sea level
µg/L	micrograms per liter
µm	micron
µS/cm	microsiemens per centimeter at 25° Celsius
mg/L	milligrams per liter
MRL	Minimum Reporting Level
MTBE	Methyl tertiary-Butyl Ether
ns	not significant
ntu	nephelometric turbidity unit
pCi/L	picocuries per liter
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
SAF	Safford Groundwater Basin
SAR	Sodium Adsorption Ratio
SDW	Safe Drinking Water
SC	Specific Conductivity
SS	San Simon sub-basin
su	standard pH units
SO4	sulfate
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
USGS	U.S. Geological Survey
VOC	Volatile Organic Compound

"One August night in the early 1890's, a hobo was put off a train at Stein Pass near the boundary of Arizona and New Mexico. Across the San Simon Valley to the west a bright light could be seen. The hobo took it to be a light at some ranch house not many miles away and struck out for it. In reality the light was a campfire at Dunn Spring where a party of cattlemen were working and had camped for the night. It is nearly twenty miles from Stein Pass station to Dunn Spring.

The man had no water, and the night was warm, so he soon began to suffer from thirst. In time the light went out as the campfire burned low, but the fellow kept the same general direction, drifting a little to the southward. There is no torture like that of thirst. I know something of it myself and have brought in men with tongues so swollen that they could not talk, and in one case a man who was unconscious. The hobo evidently suffered the tortures of the damned in that twenty miles. Just before daylight he staggered into the mouth of Brushy Canyon on the east slope of the Chiricahua Mountains, a couple of miles from Dunn Spring.

Here was running water, and his life was saved for the present."

John A. Rockfellow in *Log Of An Arizona Trail Blazer* [30]

Figure 1. Situated at the base of the Chiricahua Mountains, Dunn Spring is denoted in the arid landscape by thick riparian vegetation. Access to Dunn Spring is through a tunnel dug into the hillside.

Ambient Groundwater Quality of the San Simon Sub-Basin: A 2002 Baseline Study

By Douglas Towne

Abstract - The San Simon sub-basin (SS) of the Safford basin is located in southeastern Arizona. The basin is sparsely populated and consists of mainly of federal and State rangeland with irrigated farmland near the towns of Bowie and San Simon. The SS is drained by the ephemeral San Simon River whose headwaters are the now-dry San Simon Cienega. After heavy precipitation, the river flows north out of the SS and debouches into the Gila River near Solomon. For the purposes of this water quality report, based on water chemistry patterns, groundwater is divided into four generalized, water-bearing units: the *alluvial aquifer*, *upper aquifer*, *lower aquifer*, and mountain *bedrock*. The unconfined *alluvial aquifer* occurs south of the cienega and is differentiated from connected alluvial areas to the north in this report because of its superior groundwater quality. North of the cienega are the *upper* and *lower aquifers*. Various blue-clay units separate the groundwater perched in the *upper aquifer* from percolating to the *lower aquifer*, which occurs under either water table or artesian conditions. Where sufficiently fractured and faulted, mountain *bedrock* also provides limited supplies. Recent studies have indicated that groundwater occurs in a more complex system than outlined here, but some simplification is needed for regional water quality analysis.

A baseline groundwater quality study of the SS was conducted by the Arizona Department of Environmental Quality that consisted of 62 sites sampled in 2002 and an additional 17 sites sampled in 1997. Overall, 77 groundwater sites were sampled for inorganic constituents. Samples were also collected at selected sites for isotopes of oxygen and hydrogen (62 sites), radon (33 sites), radiochemistry (23 sites), and pesticide (4 sites) analyses.

Of the 77 sites sampled, 28 met all federal and State water quality standards. At 25 sites, concentrations of at least one constituent exceeded a health-based, federal or State water-quality standard. These enforceable standards define the maximum concentrations of constituents allowed in water supplied to the public and are based on a lifetime daily consumption of two liters per person.[34] Health-based exceedances included arsenic (2 sites under current standards, 17 sites under standards effective in 2006), beryllium (2 sites), fluoride (19 sites), nitrate (3 sites), gross alpha (3 sites) and uranium (1 site). At 49 sites, concentrations of at least one constituent exceeded an aesthetics-based, federal water-quality guideline. These are unenforceable guidelines that define the maximum concentration of a constituent that can be present in drinking water without an unpleasant taste, color, odor, or other aesthetic effect.[34] Aesthetics-based exceedances included chloride (6 sites), fluoride (35 sites), iron (5 sites), manganese (3 sites), pH (7 sites), sulfate (18 sites), and total dissolved solids or TDS (34 sites).

Groundwater composition and quality vary considerably in the sub-basin. Generally, groundwater from the alluvial aquifer and bedrock can be used without treatment for domestic purposes while that obtained from the upper or alluvial aquifer exceeds health or aesthetic standards. The limited groundwater in the *bedrock* of the Chiricahua, Dos Cabezas, Peloncillo, and Pinaleno Mountains generally meets health-based standards except for gross alpha in the granite rock of the western Dos Cabezas and Pinalenos. Though variable, groundwater chemistry is most commonly calcium-bicarbonate which is associated with recharge areas.[28] Concentrations of sodium, potassium, chloride, sulfate, fluoride, boron, and arsenic are lower in *bedrock* than in the *upper* or *lower aquifer* (ANOVA test in conjunction with Tukey test, $p \leq 0.05$). Groundwater in the *alluvial aquifer* also meets health-based standards except for fluoride at one site. The *alluvial aquifer* is the most uniform with most sites having a calcium-bicarbonate chemistry. Concentrations of TDS, sodium, chloride, sulfate, boron, and arsenic are lower in the *alluvial aquifer* than in the *upper* or *lower aquifer* (ANOVA test in conjunction with Tukey test, $p \leq 0.05$). There are few significant water quality differences between sites in the *alluvial aquifer* and *bedrock.*

Groundwater in the *lower aquifer* rarely met health-based standards because of elevated fluoride and arsenic concentrations. The high fluoride concentrations are permitted by very low calcium concentrations which result from a chemically closed system.[28] This closed system also results in a sodium-bicarbonate or sulfate groundwater chemistry. Aesthetics-based standards such as TDS, sulfate, and pH were also frequently exceeded. The most depleted or isotopically lightest waters, which may represent the oldest water in the SS, are generally associated with *lower aquifer* sites. Groundwater in the *upper aquifer* often did not meet health-based standards because of elevated fluoride or nitrate concentrations. Aesthetics-based standards for TDS and sulfate were also frequently exceeded. The least uniform geochemically, *upper aquifer* sites sometimes reflect major impacts from saline irrigation recharge and/or leakage from the *lower aquifer.* Concentrations of calcium, magnesium, hardness, and nitrate were higher in the *upper aquifer* than in the *lower aquifer* (ANOVA test in conjunction with Tukey test, $p \leq 0.05$).

INTRODUCTION

Purpose and Scope

The San Simon (SS) sub-basin is traversed by Interstate 10 in southeastern Arizona (Map 1). Most of the sub-basin lies in Graham and Cochise counties in Arizona, but a small part of it is in Grant County, New Mexico that was not sampled as part of this study. The north-south trending basin is drained by ephemeral San Simon River and is one of three arbitrarily defined sub-basins which compose the Safford groundwater basin. The Safford basin also includes (in down gradient order) the Gila Valley and San Carlos Valley sub-basins. Groundwater is the primary source for municipal, domestic, irrigation, and stock water uses in the SS.[6]

The Arizona Department of Environmental Quality (ADEQ) Groundwater Monitoring Unit designed a study to characterize the current (2002) groundwater quality conditions in the SS. Sampling by ADEQ was completed as part of the Ambient Groundwater Monitoring Program, which is based on the legislative mandate in the Arizona Revised Statutes §49-225 that authorizes:

"*...ongoing monitoring of waters of the state, including...aquifers to detect the presence of new and existing pollutants, determine compliance with applicable water quality standards, determine the effectiveness of best management practices, evaluate the effects of pollutants on public health or the environment, and determine water quality trends*."[2]

An important resource in Arizona, groundwater provides base flow for rivers, a buffer against water shortages, and protects against land subsidence. The ADEQ ambient groundwater monitoring program examined the regional groundwater quality of SS to:

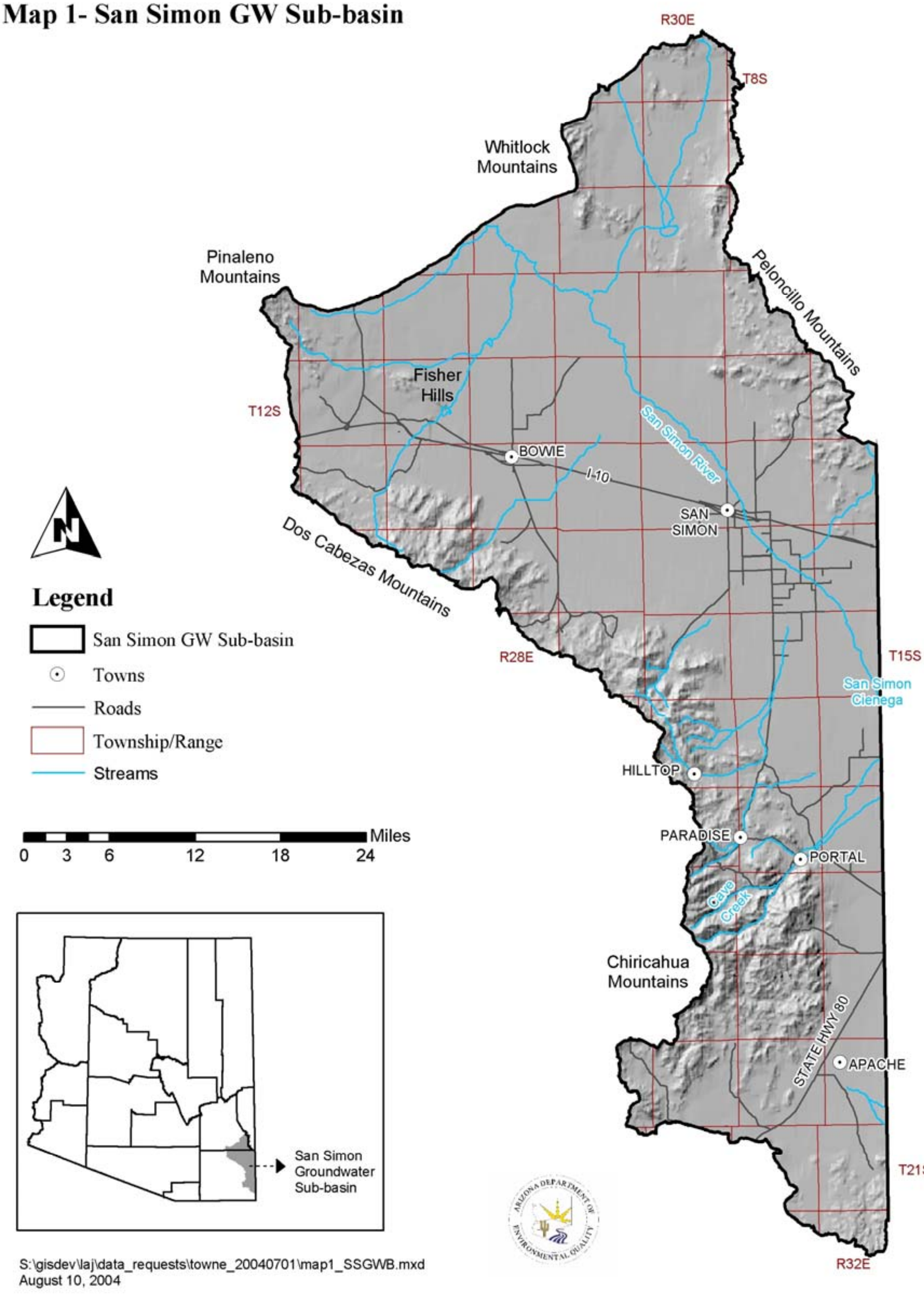
- Provide a comprehensive baseline study that will help guide the multi-state issues affecting the Gila River watershed.
- Determine if there are areas where groundwater does not currently meet U.S. Environmental Protection Agency (EPA) Safe Drinking Water Act (SDWA) water quality standards.[34]
- Examine water quality differences among the various water bearing units.

ADEQ collected samples from 77 sites for this groundwater quality assessment of the SS. Types and numbers of samples collected and analyzed include inorganic constituents (physical parameters, major ions, nutrients, and trace elements) (77 sites), oxygen and hydrogen isotopes (62 sites), radiochemistry (33 sites), radon (23 sites), and pesticides (4 sites). In addition, a surface water oxygen and hydrogen isotope sample was collected from Cave Creek near the town of Portal.

Benefits of Study – The purpose of this study was to produce a scientific report utilizing accepted sampling techniques and quantitative data analysis to investigate groundwater quality in the SS. The report's conclusion concerning groundwater quality will provide the following:

- A general characterization of regional groundwater quality. Testing all private wells for a wide variety of groundwater quality concerns would be prohibitively expensive. An affordable alternative is this type of statistically-based groundwater study characterizing regional groundwater quality conditions and identifying areas with impaired groundwater conditions.
- The water quality of private wells is seldom tested for a wide variety of possible pollutants. Arizona statutes only require well drilling contractors to disinfect for potential bacteria contamination in new wells which are used for human consumption.[2] Wells are typically not tested for other groundwater quality concerns. Thus, contamination affecting groundwater pumped from private wells may go undetected for years and have adverse health effects on users of this resource.
- A process for evaluating potential groundwater quality impacts arising from a variety of sources including mineralization, mining, agriculture, livestock, septic tanks, and poor well construction.
- Considerations for identifying future locations of public supply wells.

Map 1- San Simon GW Sub-basin



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August 10, 2004

Physical and Cultural Characteristics

Geography - The SS is located within the Chihuahua Desert section of the Basin and Range physiographic province which consists of northwest-trending alluvial basins separated by elongated fault-block mountains ranges. The SS consists of approximately 1,930 square miles which includes a portion of the sub-basin that lies within New Mexico.[6] The sub-basin is bounded to the east by the Peloncillo Mountains and, for political reasons, the New Mexico state line. To the west, its boundaries are formed by the Chiricahua, Dos Cabezas, and the extreme southern part of the Pinaleno Mountains (Figure 2). These mountains on the west side of the basin are much broader and higher than those on the east side, with Chiricahua Peak the highest point at 9,795 feet above mean sea level.

To the south, the SS is arbitrarily separated from the San Bernardino groundwater basin by a low, inconspicuous surface water divide extending from the mouth of Texas Canyon at the foot of the Chiricahua Mountains eastward to the Peloncillo Mountains three miles south of Skeleton Canyon. To the north, the SS is divided from the Gila Valley sub-basin by another arbitrary boundary that runs along a ridge line near the railroad siding of Tanque.[6]

The valley occupies a deep half-graben bounded by northwest-trending faults on the west side which are concealed beneath broad alluvial fans that merge to form bajadas.[9] The valley has the appearance of a nearly level plain with upward-curving edges.[31] The elevation of the San Simon Valley in the sub-basin varies from approximately 4,700 feet at the southern boundary to approximately 3,500 feet where the San Simon River enters the Gila Valley sub-basin.

The Arizona-portion of the SS is located in Cochise and Graham Counties. Land ownership divided among the U.S. Bureau of Land Management (36 percent), State Trust (27 percent), U.S. Forest Service (23 percent), and private entities (20 percent), National Historic Sites (1 percent), and National Monuments (1 percent).[3]

Climate - The climate of the SS is typically semiarid, characterized by hot summers and mild winters. Precipitation averages varies from about 10 inches in the valley up to 28 inches in the surrounding mountains.[36 42] Most rainfall occurs during two periods: gentle storms of long-duration during the winter and intense, short-duration monsoon storms during July and August.

Vegetation - Vegetation varies with precipitation and elevation. Low precipitation zones in valley areas are characterized by desert shrubs and grasses that are replaced by grasses, chaparral, and oak in intermediate zones. Higher precipitation zones feature pinyon-juniper forests with ponderosa pine only at the sub-basin's highest elevations. Generally among the various ranges, the Chiricahua Mountains are lush and timbered while the Dos Cabezas and Peloncillo Mountains are relatively bare of vegetation.[36]

Surface Water - Almost all stream flow in the SS is ephemeral and is generated in the mountains in response to summer and winter storms.[6] Surface flow rarely reaches the central parts of the valley because of evapotranspiration and infiltration on the upper and middle portion of alluvial fans. These areas provide most of the groundwater recharge in the sub-basin.[6] The only perennial surface flows occur in the Chiricahua Mountains and consist of short stream stretches in Cave Creek located above the town of Portal and in Price Canyon (Figure 3).[6] In general, large watercourses head in the Chiricahua Mountains in contrast to the more arid Dos Cabezas and Peloncillo Moutains.[31]

The majority of the basin is drained by San Simon River, an ephemeral watercourse. South of the town of Rodeo, New Mexico, the valley is drained through a broad shallow draw, fed by numerous creeks and washes (Figure 4) until emptying into the San Simon Cienega north of Rodeo.[6] Formerly, groundwater surfaced along a 5 mile long 1,600 acre marsh.[15] The San Simon River headwaters are at the end of the cienega. The river, usually a narrow channel with high vertical banks, follows the axis of the valley northwest out of the sub-basin until debouching into the Gila River near the farming community of Soloman. Perennial flow in the San Simon River last occurred after World War I when depressed economic conditions caused the abandonment of many farms. The uncapped irrigation wells continued their artesian flows with the groundwater eventually making it to the San Simon River.[6]

History - Historical accounts of 18th century travelers described the river as having perennial flow and containing numerous springs and marshes with the especially large San Simon Cienega located near the Arizona-New Mexico state border.[6] Colonel Phil Cooke in 1848 described the river as running bank full in the center of a lush valley.[36]

Figure 2. The San Simon sub-basin extends into New Mexico. The Land of Enchantment's state flower is the soaptree yucca with the Chiricahua Mountains. The ivory-colored, bell-shaped blossoms are sometimes called, "Our Lord's Candles."

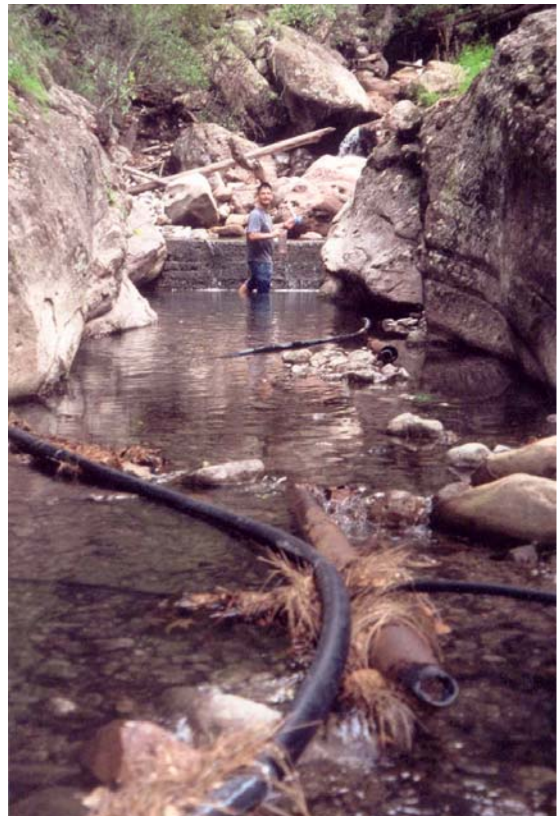


Figure 3. Jason Mahalic, a chemist with the Arizona Department of Health Services, collects a sample from Price Spring. The spring forms a short perennial stretch in Price Canyon in the southern Chiricahua Mountains. In the foreground are older steel and more recent black diversion pipe.

Figure 4. Normally dry watercourses heading in the Chiricahua Mountains are capable of discharging large amounts of water to the San Simon Valley. A summer thunderstorm created enough surface flow to make the San Simon-Paradise Road pictured here impassable for several hours.

Overgrazing in the late 1800s caused denudation of the San Simon Valley's forage. European settlement within the SS began in the late 1870s when ranchers migrating west out of Texas brought large herds of cattle to the San Simon Valley. By 1895, over 50,000 cattle grazed in the area rapidly depleting the forage.[36] Erosion was exacerbated by two periods of severe drought (1903 through 1905 and 1914 through 1915) followed by heavy rains.[25] Severe head cutting led to the formation of gullies that quickly moved up the valley with each major flood.[25] By 1934, the U.S. Soil Conservation Service found extreme erosion and almost a total loss of the once-rich grasslands.[36]

Also during the late 1800s, settlers near the town of Soloman dug a small channel and funneling levees near the mouth of the San Simon River to facilitate flow into the Gila River. This resulted in channelization by the San Simon River, which cut deeply into the formerly shallow river bed, creating a channel as much as 800 feet wide and 10 to 30 feet deep for about 60 miles upstream.[32] Tremendous erosion occurring along the San Simon River. In the San Carlos Reservoir located down gradient on the Gila River, the Bureau of Land Management estimated that approximately 30 percent of its silt originated from the San Simon River, even though only three percent of the reservoir's water came from this river.[32]

By the 1940s, the San Simon watershed was recognized as one of the most degraded watersheds in the United States.[25] The cutting and deepening of the stream channel and its major tributaries resulted in the lowering of the water table which caused perennial vegetation to die off. This led to the eventual loss of soil cover.[25] Sheet erosion occurred throughout the area and the watershed was invaded by many undesirable plant species.[25] In an attempt to restore the San Simon Valley's former lush grasslands, various agencies of the federal government have constructed an extensive system of earthen dikes, wing dams, and rock-walled barriers throughout the valley. Restoration projects have improved some areas making them more attractive to wildlife.[32]

Early settlers developed groundwater for domestic and stock purposes using shallow wells.[6] Irrigation was not attempted until artesian groundwater flow was discovered near San Simon in a deep well drilled in 1910 for the Southern Pacific Railroad.[6] Artesian flow encouraged settlement in valley areas, initially around the town of San Simon and later near the town of Bowie, and by 1915, there were 127 flowing wells.[15] Farming in the sub-basin has gone through many boom-bust cycles. In 1989, 18,000 acres were irrigated in the San Simon Valley (Figure 5).[6]

HYDROLOGY

Geology

The San Simon Valley sub-basin is a large, structural trough formed by uplift of the mountain blocks relative to the blocks underlying the basin.[6] The resulting mountains (Map 2) are composed of granite, metamorphic, sedimentary, and volcanics.[6] Erosion from these mountains gradually filled the valley with alluvium which, in generalized terms, is classified as older and younger alluvial fill.[6] Depth to bedrock typically runs from 4,000 to 6,400 feet bls though near the town of San Simon, it increases to at least 9,600 feet bls.[44]

The resulting alluvium has been classified as older and younger alluvial fill.[6] The older alluvial fill makes up the majority of sediments which are composed of interfingering beds and lenses of clay, silt, sand, and gravel.[15] The vast majority of groundwater within the sub-basin is contained within the older alluvial fill. In contrast, the younger alluvial fill consists of unconsolidated silt, sand, and gravel deposited along current stream channels.[6] These deposits are very limited in area and thickness and not important as water-bearing strata.[6]

Aquifers

Early hydrology reports divided the basin fill, which was then thought to be no more than 1,200 feet thick, into three major, though over generalized units.[31] These units, from deepest to shallowest are termed the *lower aquifer,* the *blue-clay unit*, and the *upper aquifer*.

The *lower aquifer* overlies bedrock and is the source of most of the groundwater used in the SS and may be present under either artesian or water-table conditions.[6] Artesian pressure has dramatically declined since first measured in 1913 when eight wells had an average head of 31 feet above land surface (als).[31] By 1915, 127 artesian wells had been developed and the same eight wells averaged 19 feet als.[31] By 1952, nearly all the wells had to be pumped at least part of the time for irrigation purposes (Figure 8).[39] There are currently no flowing wells providing water for irrigation purposes.[6]

Recent hydrological research has revealed that there are numerous aquifers, usually artesian, in the basin-fill rather than the singular *lower aquifer* originally thought.[44] An excellent example of the hydrologic complexity of the SS is the well log for the 1,837 foot BLM Hot Well that was sampled twice during the course of this study (Table 1). The log reveals the drillers encountered numerous aquifers and aquicludes. However, for broad water quality comparison purposes in this study, these various aquifers will be grouped together and termed the *lower aquifer*.

Early hydrology studies also talked about the presence of a middle unit, commonly called the *blue-clay unit*.[31] The *blue-clay unit* was thought to act as a confining layer between the lower and upper units.[6] It is a lacustrine deposit that was deposited when a body of water without exterior drainage, occupied most of the San Simon Valley.[39] This middle unit was thought to reach a maximum thickness of 600 feet near the town of San Simon and is encountered from 60 to 200 feet below the surface, pinching out around the margins of the basin.[15]

More recent hydrological research has revealed that the SS is much older than previously thought, that the basin was internally drained for a much longer period than previously known, and that many thick and extensive evaporate deposits have been delineated.[44] The BLM Hot Well log (Table 1) reveal that many aquicludes are present in the stratigraphy that includes several *blue-clay units* as well as other clay layers of other types.

Early hydrology studies also talked about the *upper aquifer* occurring in the upper unit of the older alluvial fill. The middle or blue-clay unit separates the groundwater perched in the *upper aquifer* from percolating downward to the *lower aquifer* except around the basin margins where it rests directly on the lower unit.[39]

Groundwater in the *upper aquifer* was historically used mainly for domestic or stock uses.[6] As the artesian pressure began to decline in the *lower aquifer* and the turbine pump efficiencies improved, groundwater in the *upper aquifer* was increasingly used for irrigation purposes in the San Simon and Bowie areas.[6] In areas south of the San Simon Cienega (Figure 10), the chief water-bearing formations are younger stream deposits that consist largely of coarse gravels.[31]

Based on the dramatic water quality differences between the southern and northern portions of the *upper aquifer*, it has been subdivided for the purposes of this report into a northern portion, termed the *upper aquifer* and a southern portion, termed the *alluvial aquifer*. The arbitrary divide between the two aquifers is near the San Simon Cienega. Although there isn't a geological boundary nor is there any aquifer material difference between the two aquifers, the dramatic water chemistry differences between the two areas necessitates this division for purposes of water quality comparisons. Groundwater in one of the aquifers can be used for domestic, municipal, and irrigation purposes; in contrast, groundwater in the other aquifer has severe use limitations. Groundwater is readily available in the *alluvial aquifer* from the cienega south to the settlement of Apache. In contrast, sub-basin areas south of Apache have limited supplies of groundwater (Figure 7).[31]

Groundwater Recharge and Discharge

The major source of groundwater recharge to the *lower aquifer* is infiltration of mountain front runoff though leakage from the *upper aquifer* through corroded well casing may occur in some areas.[6] In contrast, the *upper aquifer* receives recharge from mountain front runoff as well as from seepage from irrigation applications, stream flow infiltration, and leakage from the *lower aquifer* from corroded well casings in some areas.[15] Initially, water from the *lower aquifer* flowed into the *upper aquifer*.[31] With the lowering of artesian pressure, the *upper aquifer* now discharges into the *lower aquifer.*

Groundwater pumping is the major source of discharge in the SS with an estimated 3 million acre-feet discharged since 1915.[6] The peak pumping year (143,000 acre-feet) was 1980. By 1987, only 47,000 acre-feet was withdrawn (Figure 9). Natural groundwater flow is a minor source of discharge in the SS. Although 6,000 acre-feet of groundwater was discharged annually to the downgradient Gila Valley sub-basin, this amount is currently much less as groundwater pumping has flattened, and even reversed, this gradient.[6] The outflow southward across the surface water boundary into the San Bernardino Valley basin has not been quantified. Unregulated artesian flow and evapotranspiration from the San Simon Cienega, once major sources of discharge from the sub-basin, are now negligible factors (Figure 10).[6]

Table 1. Well log for BLM Hot Well Dunes Recreation Area

Drill Depth	Substrate	Comments
0– 40	Sand	
40 – 120	Sand and shale	
120 – 135	Sand, shale, and water	Aquifer
135 – 155	Brown and blue shale	Aquitard
155 – 165	Blue shale	Aquitard
165 – 180	Sand and water	Aquifer
180 – 205	Brown and blue shale	Aquitard
205 – 215	Water and sand	Aquifer
215 – 230	Brown and blue shale	Aquitard
230 – 240	Water and sand	Aquifer
240 – 416	Gray shale	Aquiclude
416 – 640	Brown and light shale	Aquiclude
640 – 650	Sandy shale and salt water	Salt water aquifer
650 – 740	Brown shale	Aquiclude
740 – 1015	Blue shale	Aquiclude
1015 – 1022	Sand and salt water	Salt water aquifer
1022 – 1045	Brown shale	Aquiclude
1045 – 1078	Brown sandy shale	Aquiclude
1078 – 1094	Slight sandy shale	Aquiclude
1094 – 1096	Shells gypsum	Evaporate layer
1096 – 1104	Brown shale	Aquiclude
1104 – 1115	Light gypsum shale	Evaporate
1115 – 1125	Sand and water	Aquifer
1125 – 1165	Brown shale	
1165 – 1185	Sand and water	Aquifer
1185 – 1197	Brown shale	
1197 – 1208	Sand and salt water	Salt water aquifer
1208 – 1212	Blue shale	
1212 – 1260	Sand, gravel and salt water	Salt water aquifer
1260 – 1274	Brown and green shale	
1274 – 1284	Sand and salt water	Salt water aquifer
1284 – 1323	Brown sandy shale	
1323 – 1328	Red clay (hot)	
1328 – 1350	Brown sandy shale	
1350 – 1352	Sand and salt water	Salt water aquifer
1352 – 1363	Brown shale	
1363 – 1364	Coarse gravel and water	Artesian aquifer
1364 – 1369	Fine sand and water	Aquifer
1369 – 1405	Coarse sand and water	Aquifer
1405 – 1837	Conglomerate, sand, gravel, shells lime, sandstone, etc	No water discovered

Map 2 - San Simon GW Sub-basin
Rock Types and Sample Locations

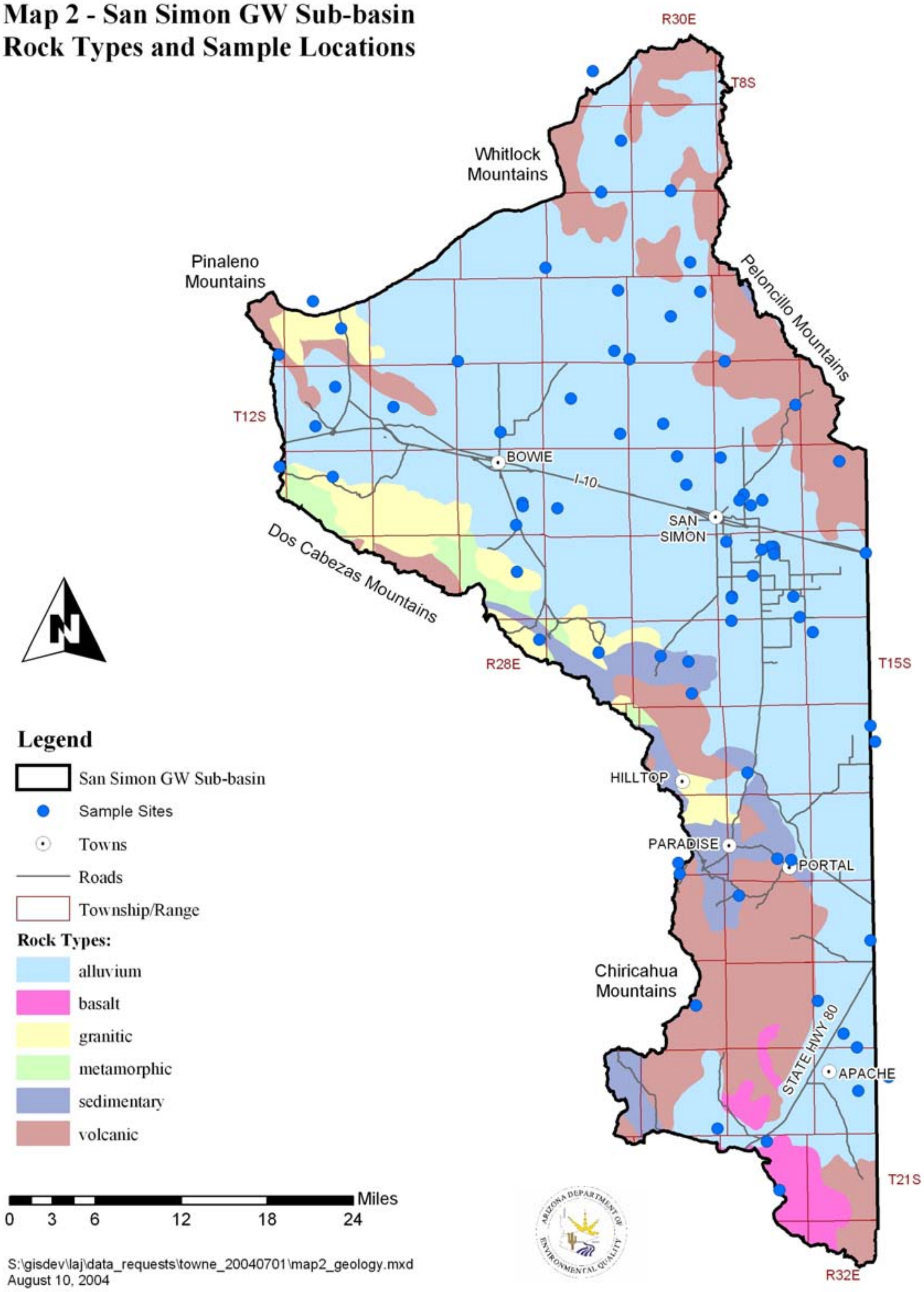


Figure 5. Jason Mahalic samples an irrigation well powered by a turbine pump south of the town of San Simon. This shallow well taps the upper aquifer and supplies a healthy cotton crop despite the water's "very high salinity" and "high sodium" irrigation classification.[35]

Figure 6. Joe Harmon samples Wood Canyon windmill in the Pinaleno Mountains. Near an area of granite rock, water from the well exceeded health-based drinking water standards for gross alpha and uranium.[23]

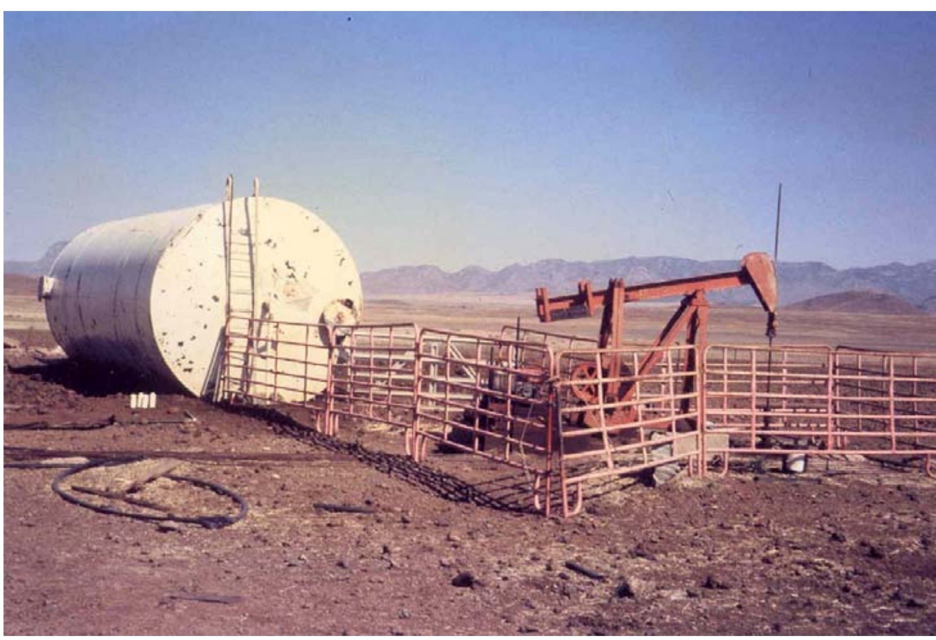


Figure 7. A vintage pump jack produces water for livestock use that is stored in a former underground storage tank. This 900 foot deep well is the most southerly (or up gradient) sample collected in the San Simon sub-basin. Groundwater from this well, like most pumping from the alluvial aquifer, meets all health-based water quality standards.

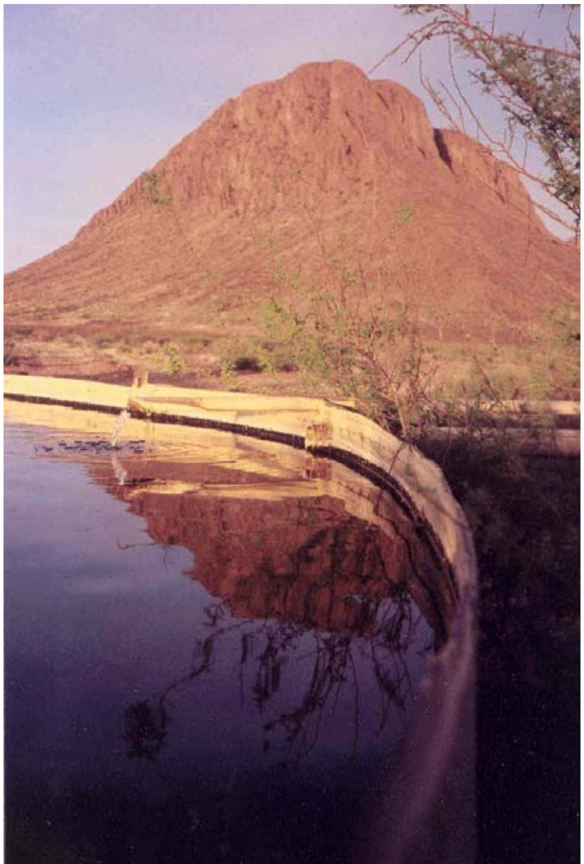


Figure 8. Groundwater from Butte Well empties into this storage tank for livestock use in the San Simon Valley. The appropriately named Orange Butte looms in the background.

Figure 9. Cross J Windmill is located at the northern base of the Chiricahua Mountains. Across the valley, the Peloncillo Mountains can be seen which provides an idea of the vast expanse of the San Simon sub-basin.

Figure 10. Located on the border with New Mexico, the San Simon Cienega was once a marsh. Although now dry, the presence of cottonwood trees indicates shallow groundwater is still present in the area.

Groundwater Movement, Storage and Levels

The direction of groundwater movement generally mirrors surface-water drainage moving from the surrounding mountain fronts toward the middle of the sub-basin and then down the valley from the south to the north and northwest.[6] This natural flow direction is now interrupted by cones of depression from irrigation pumping near Bowie and San Simon.[6] South of Apache, the groundwater flow is to the south. Prior to development, there was an estimated 25 million acre-feet of recoverable groundwater in the basin-fill material to a depth of 1,200 feet below land surface.[6] Available water level information indicates that generally declines have occurred in the *lower aquifer* throughout the basin during a 25 year period between 1962 - 1987 with the steepest declines (up to 211 feet bls) where irrigated farming is concentrated.[6] Some related land subsidence has also occurred in the Bowie and San Simon areas. Other indications of declining groundwater levels are now dry historic wetlands such as the Whitlock Cienega. There is generally not enough water level data for the upper aquifer to assess time trend changes.[6]

GROUNDWATER SAMPLING RESULTS

To characterize the regional groundwater quality of the SS, in 2002 ADEQ personnel sampled 64 groundwater sites consisting of 58 wells and 6 springs. Fifteen wells previously sampled by ADEQ in 1997 for a watershed study were also utilized in this report including two wells that were resampled in 2002 (Figure 11). Thus, this groundwater quality study is composed of water quality results from 77 sites in the San Simon sub-basin (Map 2).

The 71 wells consisted of 29 windmills for livestock use, 17 irrigation wells with turbine pumps (Figure 12), 23 wells with submersible pumps (14 for livestock use and 9 for domestic use), and 2 artesian wells for livestock use. Of the 6 springs, 3 were used for drinking water purposes and 3 were for stock and/or wildlife use (Figure 13). Information on locations and characteristics of these groundwater sample sites is provided in Appendix A.

The following types of samples were collected:

- Inorganic samples at 77 sites;
- Hydrogen and oxygen isotope samples at 62 sites;
- Radon samples at 33 sites;
- Radiochemistry samples at 23 sites; and
- Pesticide samples at 4 sites.

Water Quality Standards/Guidelines

The ADEQ ambient groundwater monitoring program characterizes regional groundwater quality. One of the most important determinations ADEQ makes concerning the collected samples is how the analytical results compare to various drinking water quality standards. Three sets of drinking water standards which reflect the best current scientific and technical judgment available on the suitability of water for drinking purposes were used to evaluate the suitability of these groundwater sites for domestic purposes:

- Federal Safe Drinking Water (SDW) Primary Maximum Contaminant Levels (MCLs). These enforceable health-based standards establish the maximum concentration of a constituent allowed in water supplied by public systems.[34]

- State of Arizona Aquifer Water-Quality Standards apply to aquifers that are classified for drinking water protected use.[34] All aquifers within Arizona are currently regulated for drinking water use. These enforceable State standards are almost identical to the federal Primary MCLs.

- Federal SDW Secondary MCLs. These non-enforceable aesthetics-based guidelines define the maximum concentration of a constituent that can be present without imparting unpleasant taste, color, odor, or other aesthetic effect on the water.[34]

Health-based drinking water quality standards such as Primary MCLs are based on a lifetime consumption of two liters of water per day and, as such, are chronic not acute standards.[34]

Water Quality Standard/Guideline Exceedances

Of the 77 sites sampled for the study, only 28 (36 percent) met all SDW Primary and Secondary MCLs.

Health-based Primary MCL water quality standards and State aquifer water quality standards were exceeded at 25 of 77 sites (33 percent) (Map 3) (Table 2). Constituents exceeding Primary MCLs include arsenic (2 sites under current standards, 17 sites under standards which take effect in 2006) (Map 4), beryllium (2 sites) fluoride (19 sites) (Map 4), gross alpha (3 sites), nitrate (3 sites) (Map 5), and uranium (1 site). Potential health effects of these chronic Primary MCL exceedances are provided in Table 2.

Aesthetics-based Secondary MCL water quality guidelines were exceeded at 48 of 77 sites (62 percent) (Map 3)(Table 3). Constituents above Secondary MCLs include: chloride (6 sites), fluoride (35 sites), iron (5 sites), manganese (3 sites), pH (7 sites), sulfate (18 sites)(Map 6), and TDS (34 sites) (Map 6). Potential effects of these Secondary MCL exceedances are provided in Table 3.

Radon is a naturally occurring, intermediate breakdown product from the radioactive decay of uranium-238 to lead-206.[12] There are widely conflicting opinions on the risk assessment of radon in drinking water, with proposed drinking water standards varying from 300 to 4,000 pCi/L.[12] Twenty-seven (27) of the 33 sites sampled for radon exceeded the 300 pCi/L standard; one exceeded the 4,000 pCi/L standard.

Four sites were samples for Groundwater Protection List (GWPL) of currently-registered pesticides and Clean Water Act (CWA) 608 List of banned chlorinated pesticides. Analytical results revealed no detections of any pesticides or their products of degradation at any site.

Suitability for Irrigation

The suitability of groundwater at each sample site was assessed as to its suitability for irrigation use based on salinity and sodium hazards. With increasing salinity, leaching, salt tolerant plants, and adequate drainage are necessary. Excessive levels of sodium are known to cause physical deterioration of the soil.[35] Irrigation water may be classified using specific conductivity (SC) and the Sodium Adsorption Ratio (SAR) in conjunction with one another.[35]

Groundwater sites in the SS display a wide range of irrigation water classifications with salinity hazards generally greater than sodium hazards. The 77 sample sites are divided into the following salinity hazards: low or C1 (7), medium or C2 (38), high or C3 (26), and very high or C4 (6). Likewise, the 77 sample sites are divided into the following sodium or alkali hazards: low or S1 (55), medium or S2 (8), high or S3 (5), and very high or S4 (9). Irrigation water classifications using both salinity and sodium hazards are found in Table 4.

Analytical Results

Analytical inorganic and radiochemistry results of the 77 sample sites are summarized (Table 5**)** using the following indices: minimum reporting levels (MRLs), number of sample sites over the MRL, upper and lower 95 percent confidence intervals ($CI_{95\%}$), and the median and mean. Confidence intervals are a statistical tool which indicates that 95 percent of a constituent's population lies within the stated confidence interval. Specific constituent information for each groundwater site is found in Appendix B.

Figure 11. A 1957 Buick is permanently parked in front of Antelope Well, a windmill that was sampled for this study both in 1997 and 2002. Based on results from this windmill and another well, sub-basin groundwater data from the two studies were judged able to be used interchangeably.[37]

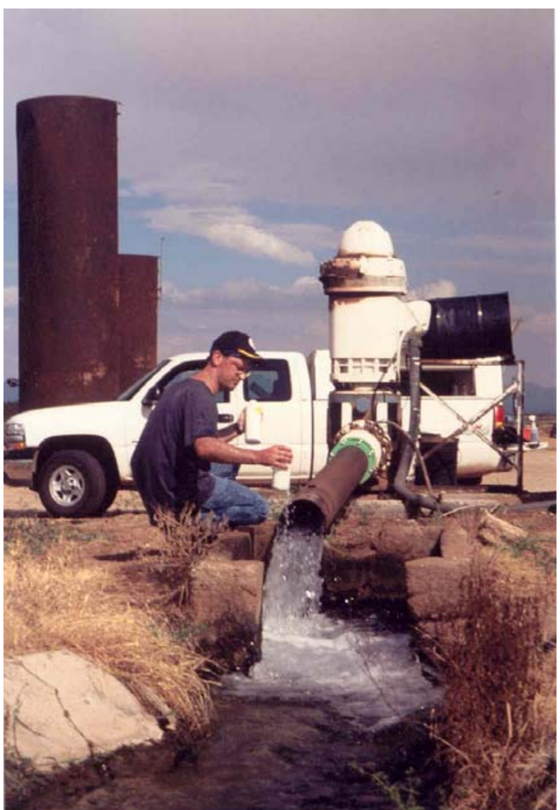


Figure 12. A turbine pump produces water from an 800-foot well near Bowie. Jason Mahalic is collecting a grab sample from the pipe discharging into the irrigation ditch. Generally groundwater sites in the Bowie area met health-based water quality standards.

Figure 13. Extremely fresh groundwater is found atop the Chiricahua Mountains at Lower Rustler Spring. TDS concentrations of only 60 mg/L were found in this sample collected by Cheri Horsley.

Map 3 - San Simon GW Sub-basin Water Quality Exceedances

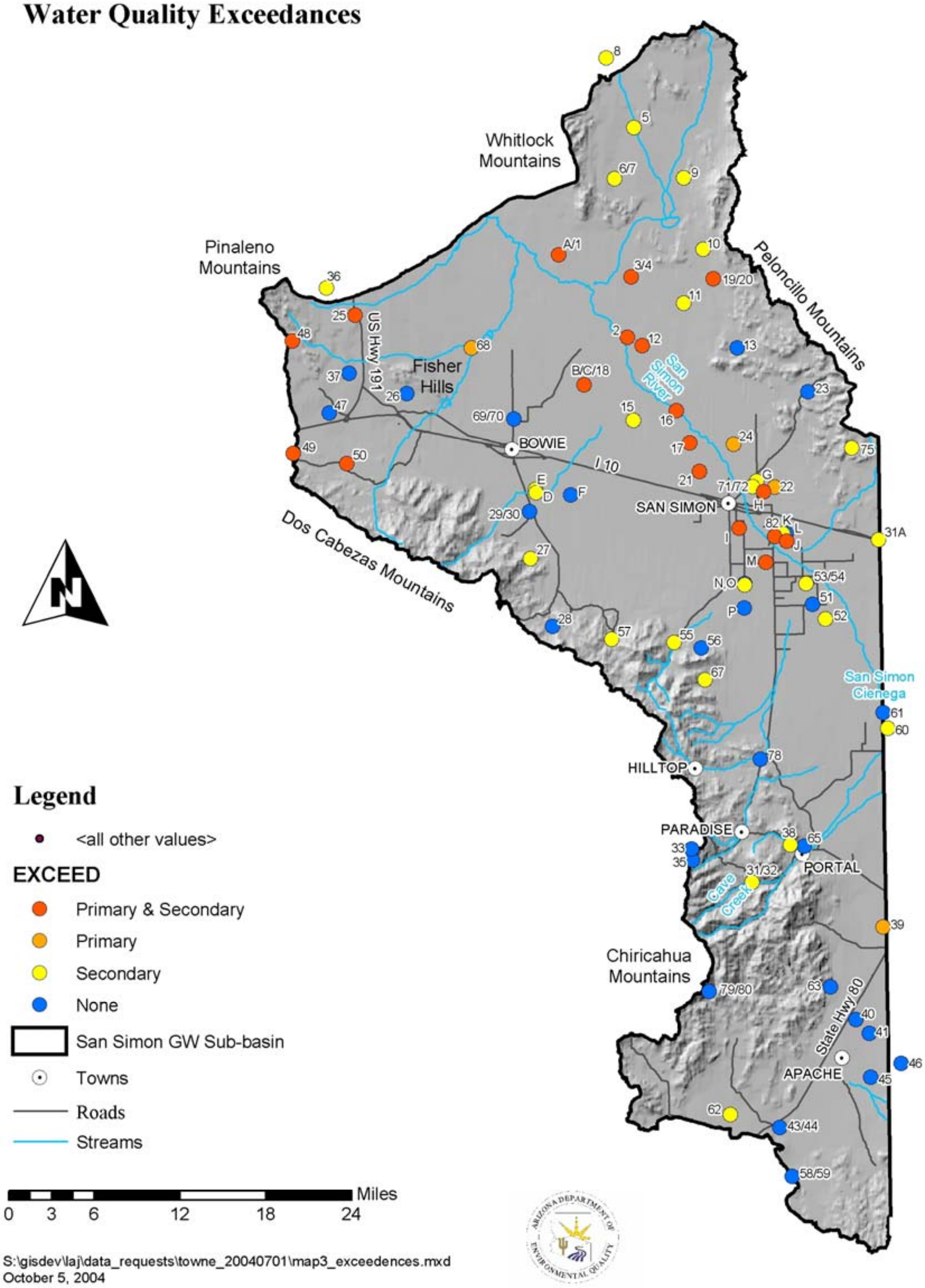


Table 2. SS Sites Exceeding Health-Based Water Quality Standards (Primary MCLs)

Constituent	Primary MCL	Sites Exceeding Primary MCL	Concentration Range of Exceedances	Potential Health Effects of MCL Exceedances *
Nutrients				
Nitrite (NO_2-N)	1.0	0		
Nitrate (NO_3-N)	10.0	3	18 - 31	Methemoglobinemia
Trace Elements				
Antimony (Sb)	0.006	0		
Arsenic (As)	0.05 0.01**	2 16	0.053 - 0.060 0.011 - 0.0060	Dermal and nervous system toxicity
Barium (Ba)	2.0	0		
Beryllium (Be)	0.004	2	0.00061 - 0.0019	Bone and lung damage
Cadmium (Cd)	0.005	0		
Chromium (Cr)	0.1	0		
Copper (Cu)	1.3	0		
Fluoride (F)	4.0	19	4.1 - 17	Skeletal damage
Lead (Pb)	0.015	0		
Mercury (Hg)	0.002	0		
Nickel (Ni)	0.1	0		
Selenium (Se)	0.05	0		
Thallium (Tl)	0.002	0		
Radiochemistry Constituents				
Gross Alpha	15	3	16-36 pCi/L	Cancer
Ra-226 + Ra-228	5	0		
Uranium	30	1	34 µg/L	Cancer and kidney toxicity

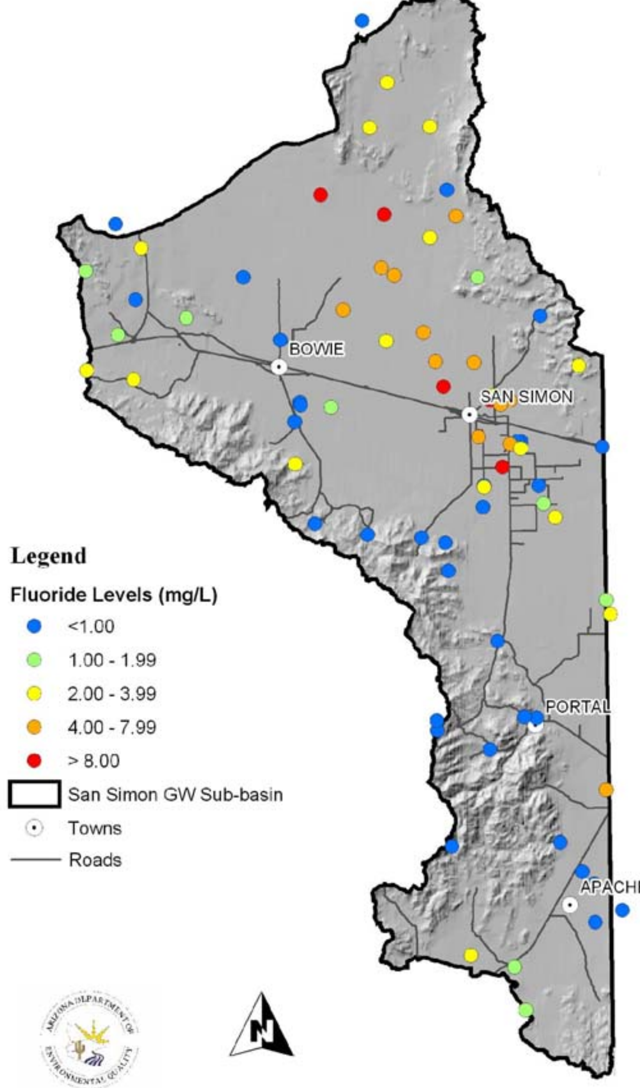
All units in mg/L except gross alpha and radium-226+228 (pCi/L), and uranium (µg/L).

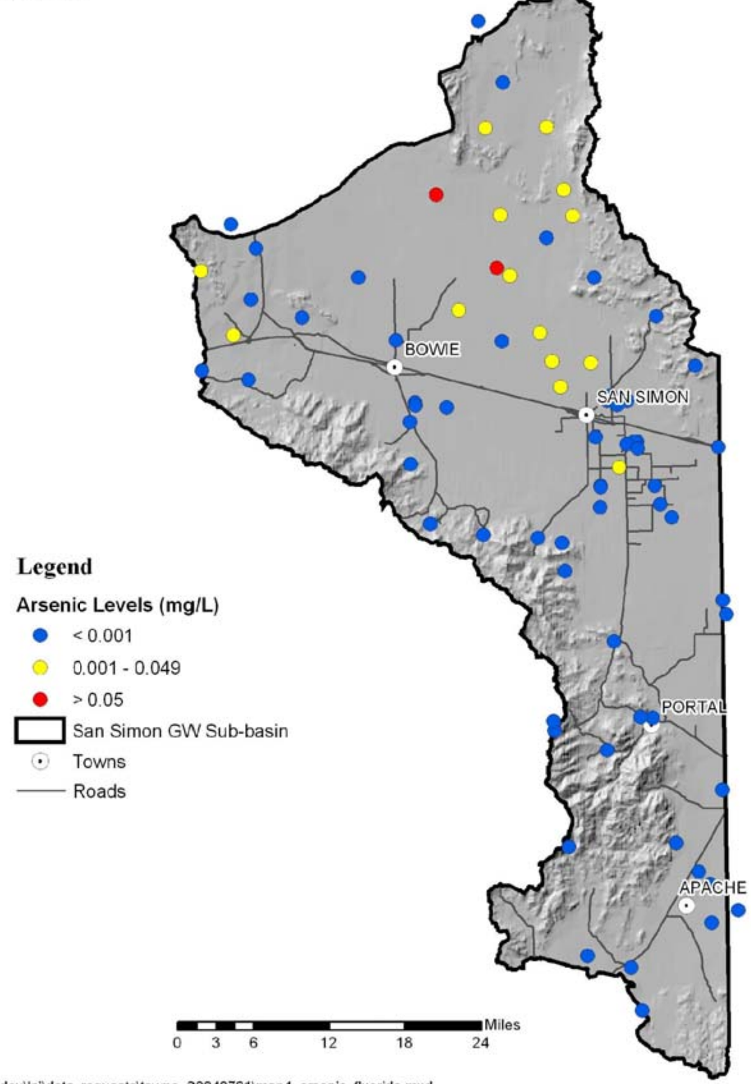
* Health-based drinking water quality standards such as Primary MCLs are based on a lifetime consumption of two liters of water per day (USEPA). Therefore, these are considered chronic, not acute, standards.

** Revised arsenic primary MCL scheduled to be implemented in 2006

Source: [34 38]

Map 4 - San Simon GW Sub-Basin
Fluoride and Arsenic





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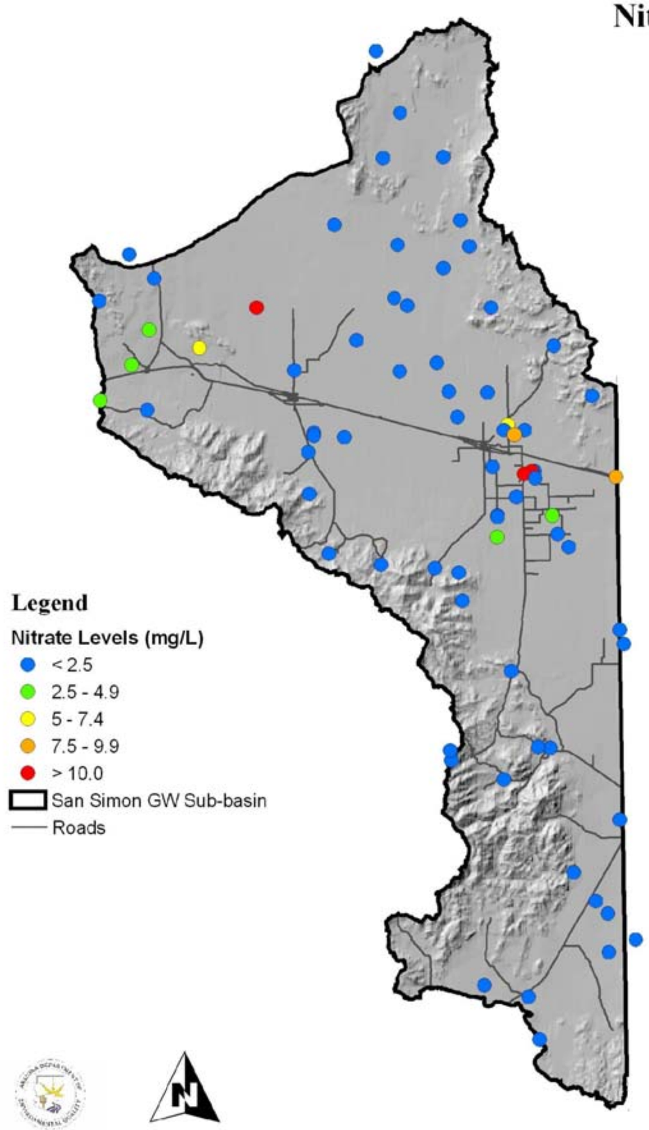
Map 5 - San Simon GW Sub-Basin
Nitrate and Hardness



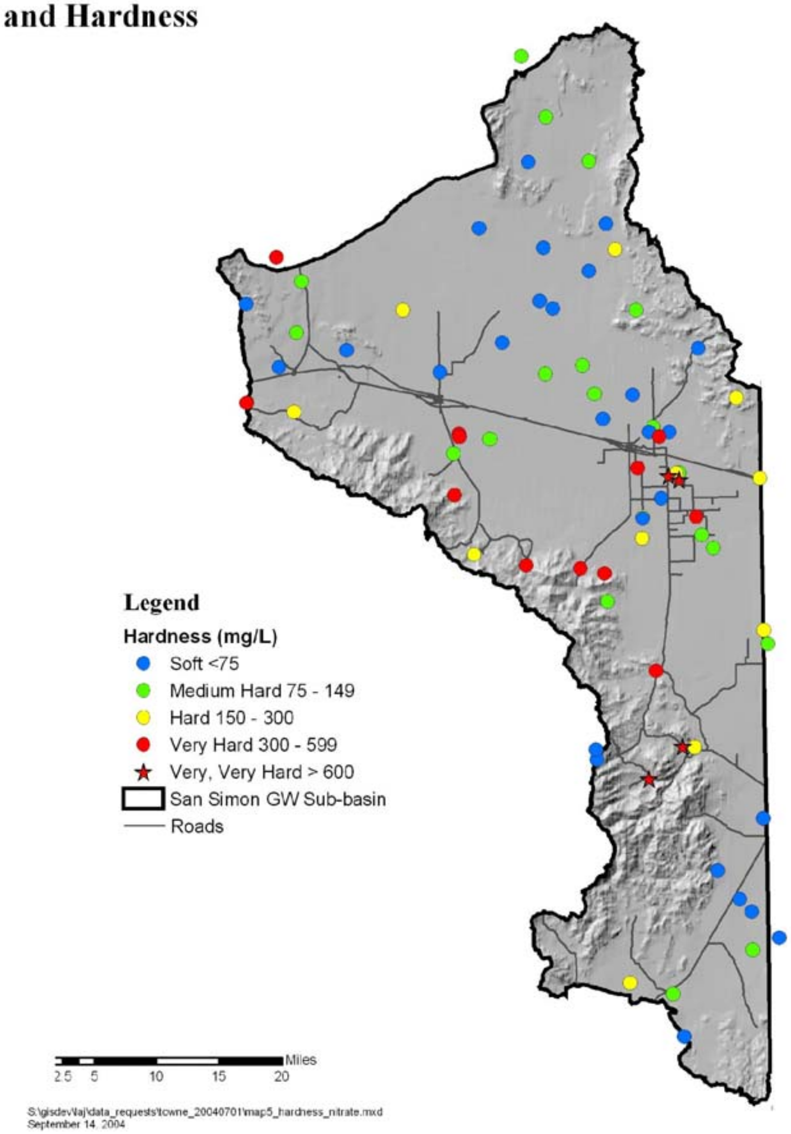


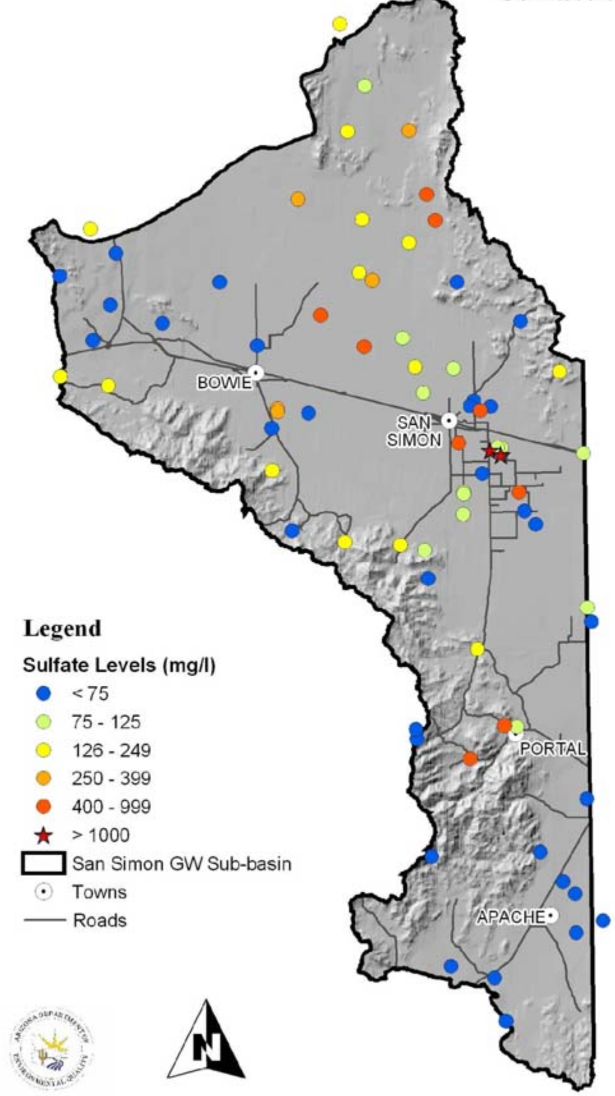
Table 3. SS Sites Exceeding Aesthetics-Based Water Quality Standards (Secondary MCLs)

Constituents	Secondary MCL	Sites Exceeding Secondary MCLs	Concentration Range of Exceedances	Aesthetic Effects of MCL Exceedances
Physical Parameters				
pH - field	6.5 to 8.5	7	8.64 - 9.03	Corrosive water
General Mineral Characteristics				
TDS	500	34	530 - 4600	Unpleasant taste
Major Ions				
Chloride (Cl)	250	6	280 - 415	Salty taste
Sulfate (SO_4)	250	18	270 - 2900	Rotten-egg odor, unpleasant taste, and laxative effect
Trace Elements				
Fluoride (F)	2.0	35	2 - 17	Mottling of teeth enamel
Iron (Fe)	0.3	5	0.37 - 4.6	Rusty color, reddish stains, and metallic tastes
Manganese (Mn)	0.05	3	0.058 - 0.16	Black oxide stains and bitter, metallic taste
Silver (Ag)	0.1	0		
Zinc (Zn)	5.0	0		

All units mg/L except pH is in standard units (su).

Source: [20 34 38]

Map 6 - San Simon GW Sub-Basin
Sulfate and Total Dissolved Solids



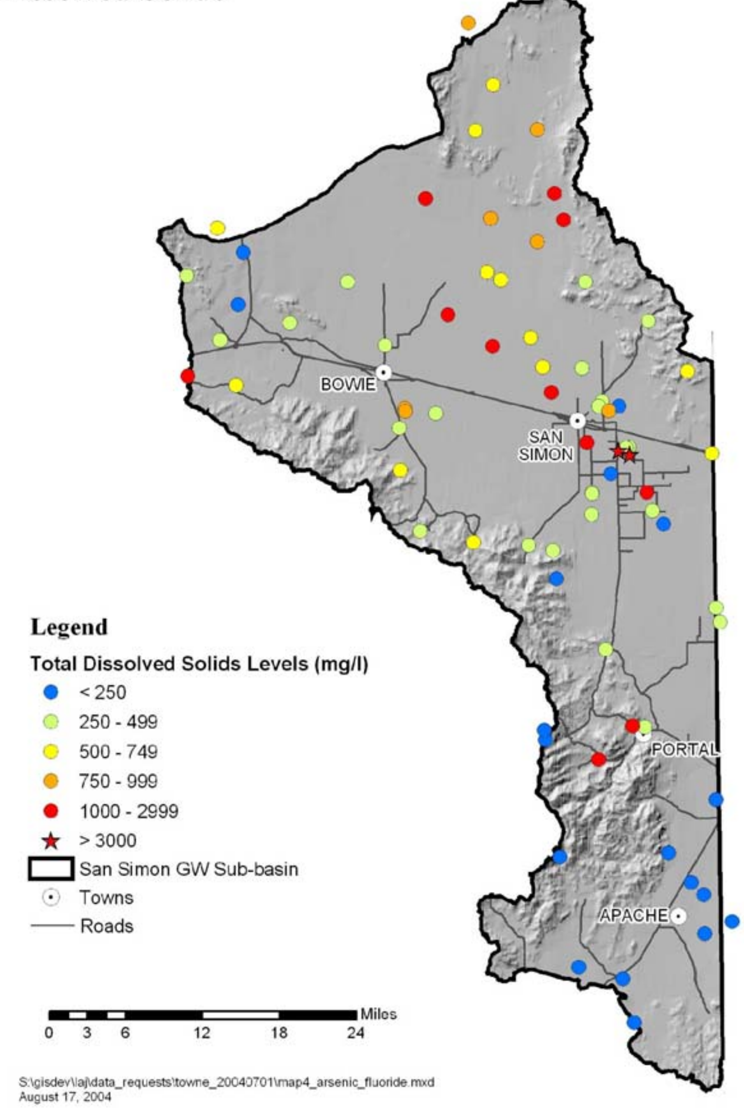


Table 4. Classification of SS Groundwater Sample Sites for Irrigation Use

	Salinity Hazard Low (C1)	Salinity Hazard Medium (C2)	Salinity Hazard High (C3)	Salinity Hazard Very High (C4)
Sodium Hazard Very High (S4)	0 (C1 - S4)	0 (C2 - S4)	5 (C3 - S4)	4 (C4 - S4)
Sodium Hazard High (S3)	0 (C1 - S3)	2 (C2 - S3)	2 (C3 - S3)	1 (C4 - S3)
Sodium Hazard Medium (S2)	0 (C1 - S2)	1 (C2 - S2)	6 (C3 - S2)	1 (C4 - S2)
Sodium Hazard Low (S1)	7 (C1 - S1)	35 (C2 - S1)	13 (C3 - S1)	0 (C4 - S1)

Low-Salinity Water (C1) - can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.

Medium-Salinity Water (C2) - can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

High-Salinity Water (C3) - cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

Very High-Salinity Water (C4) - is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected.

Low-Sodium Water (S1) - can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stone-fruit trees and avocados may accumulate injurious concentrations of sodium.

Medium-Sodium Water (S2) - will present an appreciable sodium hazard in fine-textured soils having high cation-exchange-capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils with good permeability.

High-Sodium Water (S3) - may produce harmful levels of exchangeable sodium in most soils and will require special soil management–good drainage, high leaching, and organic matter additions. Gypsiferous soils may not develop harmful levels of exchangeable sodium, except that amendments may not be feasible with waters of very high salinity.

Very High-Sodium Water (S4) - is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.[35]

Table 5. Summary Statistics for SS Groundwater Quality Data

Constituent	Minimum Reporting Limit (MRL)	Number of Samples Over MRL	Lower 95% Confidence Interval	Median	Mean	Upper 95% Confidence Interval	Mean of Cave Creek Above Portal, AZ
Physical Parameters							
Temperature (^oC)	N/A	71	24.2	24.9	25.4	26.6	13.6
pH-field (su)	N/A	74	7.67	7.78	7.79	7.91	7.77
pH-lab (su)	0.01	74	7.57	7.70	7.70	7.83	7.71
Turbidity (ntu)	0.01	73	0.47	0.25	3.36	6.24	9.91
General Mineral Characteristics							
Total Alkalinity	2.0	74	154	155	177	299	108
Phenol. Alk.	2.0	9	> 85% of data below MRL				
SC-field (µS/cm)	N/A	74	726	622	933	1141	367
SC-lab (µS/cm)	N/A	74	745	630	958	1172	382
Hardness-lab	10.0	70	139	110	191	243	183
TDS	10.0	74	486	420	652	817	262
Major Ions							
Calcium	5.0	74	44	32	62	79	65
Magnesium	1.0	69	7.3	5.7	9.9	12.5	5.7
Sodium	5.0	74	98	61	138	178	8
Potassium	0.5	72	2.8	2.4	3.6	4.4	1.6
Bicarbonate	2.0	74	185	181	211	237	131
Carbonate	2.0	6	> 85% of data below MRL				
Chloride	1.0	74	41	18	63	85	2.6
Sulfate	10.0	71	127	110	217	307	87
Nutrients							
Nitrate (as N)	0.02	66	1.0	0.6	2.2	3.4	--
Nitrite (as N)	0.02	3***	> 85% of data below MRL				--
Ammonia	0.02	8	> 85% of data below MRL				--
TKN	0.05	33	0.08	0.03	0.13	0.18	--
Total Phosphorus	0.02	23	0.015	0.010	0.021	0.027	--

All units mg/L except where noted with physical parameters   Source for Cave Creek: ADEQ Surface Water Database

Table 5. Summary Statistics for SS Groundwater Quality Data—Continued

Constituent	Minimum Reporting Limit (MRL)	Number of Samples Over MRL	Lower 95% Confidence Interval	Median	Mean	Upper 95% Confidence Interval	Mean of Cave Creek near Portal, AZ
Trace Elements							
Antimony	0.005	0	> 85% of data below MRL				--
Arsenic	0.01	17	0.0034	0.0025	0.0127	0.0219	--
Barium	0.1	1	> 85% of data below MRL				--
Beryllium	0.0005	2	> 85% of data below MRL				--
Boron	0.1	34	0.15	0.05	0.23	0.34	--
Cadmium	0.001	1	> 85% of data below MRL				--
Chromium	0.01	2	> 85% of data below MRL				--
Copper	0.01	9	> 85% of data below MRL				--
Fluoride	0.20	72	2.0	1.3	2.8	3.6	0.46
Iron	0.1	13	0.029	0.050	0.180	0.331	--
Lead	0.005	1	> 85% of data below MRL				--
Manganese	0.05	3	> 85% of data below MRL				--
Mercury	0.0005	1	> 85% of data below MRL				--
Nickel	0.1	0***	> 85% of data below MRL				--
Selenium	0.005	6	> 85% of data below MRL				--
Silver	0.001	0	> 85% of data below MRL				--
Thallium	0.005	0	> 85% of data below MRL				--
Zinc	0.05	29	0.056	0.025	0.142	0.229	--
Radiochemical Constituents							
Radon*	Varies	33	479	533	789	1099	--
Gross Alpha*	Varies	23	3.0	4.6	6.5	10.0	--
Gross Beta*	Varies	21	3.0	3.1	5.2	7.4	--
Ra-226*	Varies	0	> 85% of data below MRL				--
Ra-228*	Varies	4	> 85% of data below MRL				--
Uranium**	Varies	3	> 85% of data below MRL				--

All units mg/L except * = pCi/L and ** = µg/L
*** = Only 64 sites sampled for nickel
Source for Cave Creek: ADEQ Surface Water Database

GROUNDWATER COMPOSITION

Groundwater in the SS was characterized by qualitative classifications, chemistry, and cross-correlation of constituent concentrations.

General Summary

Groundwater in the SS is generally slightly alkaline, fresh, and hard as indicated by pH values and TDS and hardness concentrations. TDS concentrations (Map 6) were considered fresh (below 1,000 mg/L) at 63 sites while 12 sites were slightly saline (1,000 to 3,000 mg/L) while 2 sites were moderately saline (3,000 to 10,000 mg/L).[18] Levels of pH were slightly acidic (below 7 SU) at 2 sites and slightly alkaline (above 7 SU) at 75 sites.[18] Hardness concentrations (Map 5) were divided into soft (28 sites), moderately hard (18 sites), hard (13 sites), and very hard (18 sites).[13]

Nutrient concentrations were generally low with nitrate (Map 5), TKN, and total phosphorus detected at more than 15 percent of the sites. Nitrate (as nitrogen) concentrations were divided into natural background (16 sites < 0.2 mg/L), may or may not indicate human influence (50 sites between 0.2 - 3.0 mg/L), may result from human activities (8 sites between 3.0 - 10 mg/L), and probably result from human activities (3 sites > 10 mg/L).[24]

Most trace elements such as antimony, barium, beryllium, cadmium, chromium, copper, lead, manganese, mercury, nickel, selenium, silver, and thallium were rarely–if ever--detected. Only arsenic, boron, fluoride, iron, and zinc were detected at more than 15 percent of the sites.

Groundwater Chemistry

The chemical composition of sampled sites is shown in Map 7 as well as illustrated using Piper trilinear diagrams.

- The cation triangle diagram (lower left in Figure 14) shows that the dominant (> 50 percent) cation is calcium at 26 sites, sodium at 39 sites, magnesium at 0 sites, and mixed at 12 sites.
- The anion triangle diagram (lower right in Figure 14) shows that the dominant anion (> 50 percent) is bicarbonate at 46 sites, sulfate at 13 sites, chloride at 0 sites, and mixed at 18 sites.
- The cation-anion diamond diagram (in center of Figure 14) shows that the groundwater chemistry is calcium-bicarbonate at 20 sites, sodium-bicarbonate at 17 sites, sodium-mixed at 15 sites, mixed-bicarbonate at 9 sites, sodium-sulfate at 7 sites, calcium-sulfate at 4 sites, calcium-mixed and mixed-sulfate at two sites apiece, and mixed-mixed at 1 site.

Overall Constituent Co-variation

The co-variation of constituent concentrations was determined to scrutinize the strength of the associations. The results of each combination of constituents were examined for statistically-significant positive or negative correlations. A ***positive correlation*** occurs when, as the level of a constituent increases or decreases, the concentration of another constituent also correspondingly increases or decreases. A ***negative correlation*** occurs when, as the concentration of a constituent increases, the concentration of another constituent decreases, and vice-versa. A positive correlation indicates a direct relationship between constituent concentrations; a negative correlation indicates an inverse relationship.

Many significant correlations occurred among the 77 SS sites (Pearson Correlation Coefficient test, $p \leq 0.05$). The results are provided in Table 6. Positive correlations that should be highlighted are calcium-sulfate, sodium-chloride and sodium-fluoride (Figure 15). TDS concentrations are best predicted among major ions and cations by sodium concentrations (Figure 15) while among anions, sulfate is the best predictor (multiple regression analysis, $p \leq 0.01$).

Map 7 - San Simon GW Sub-basin Water Chemistry

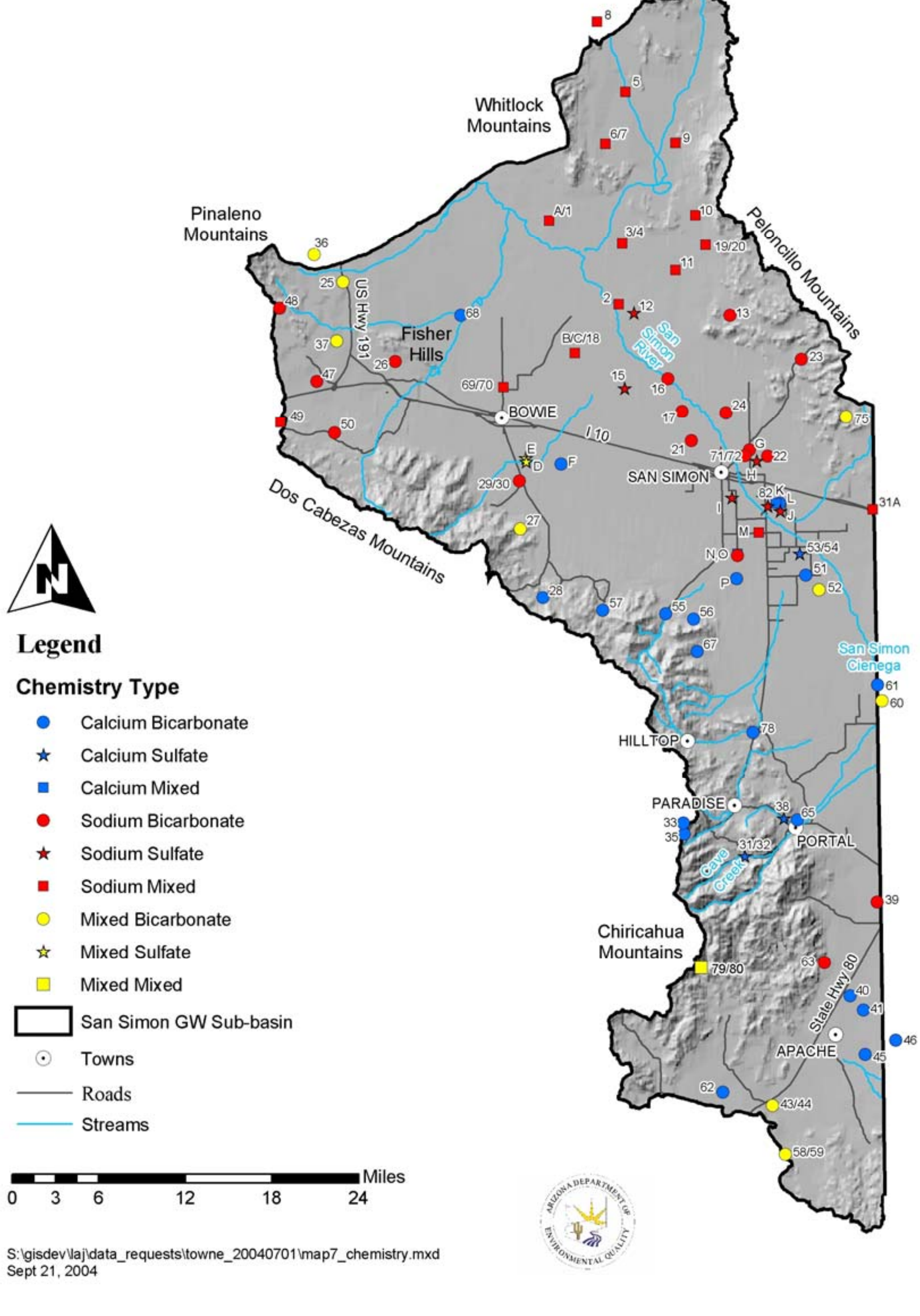


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Figure 15. Piper Trilinear Diagram

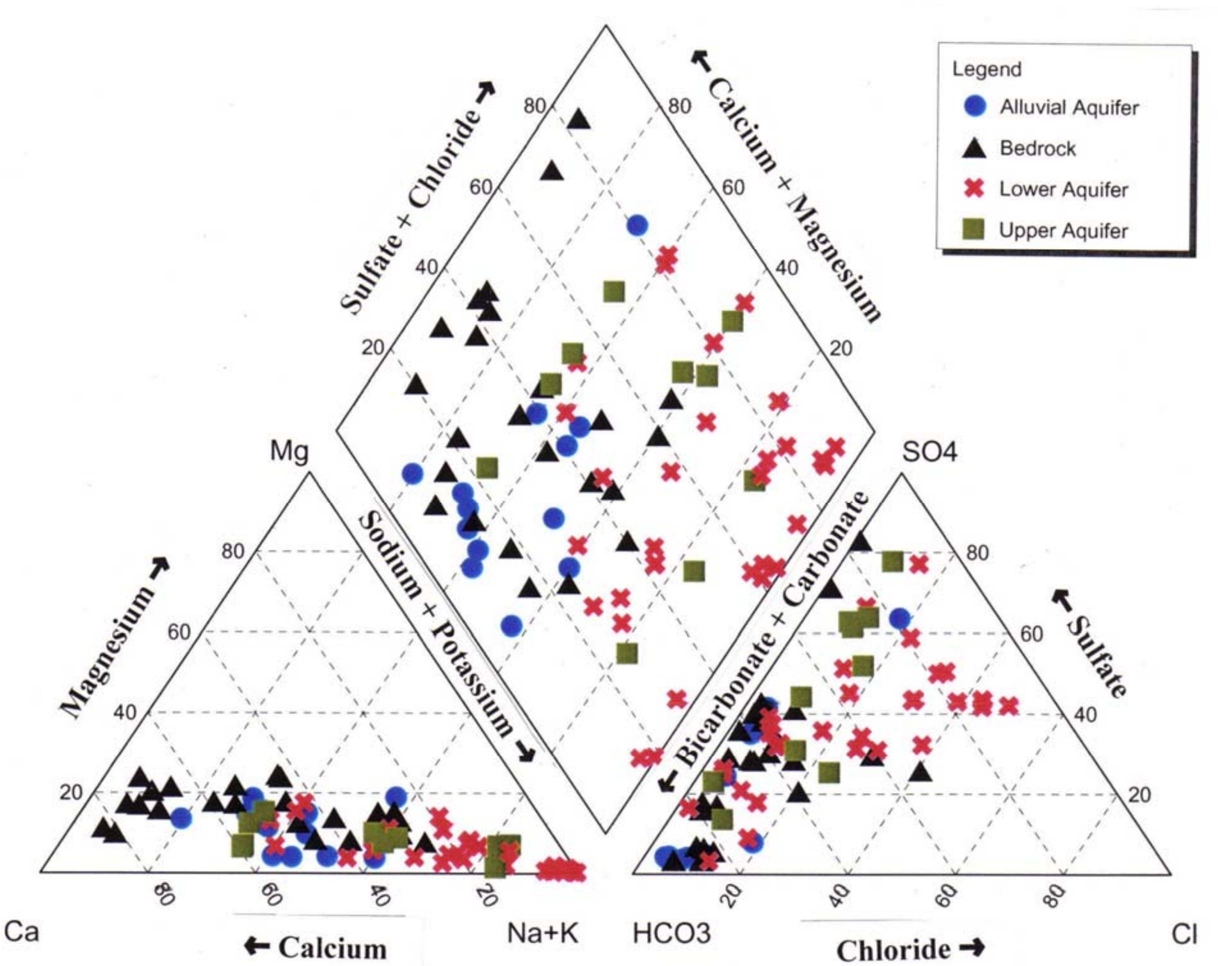
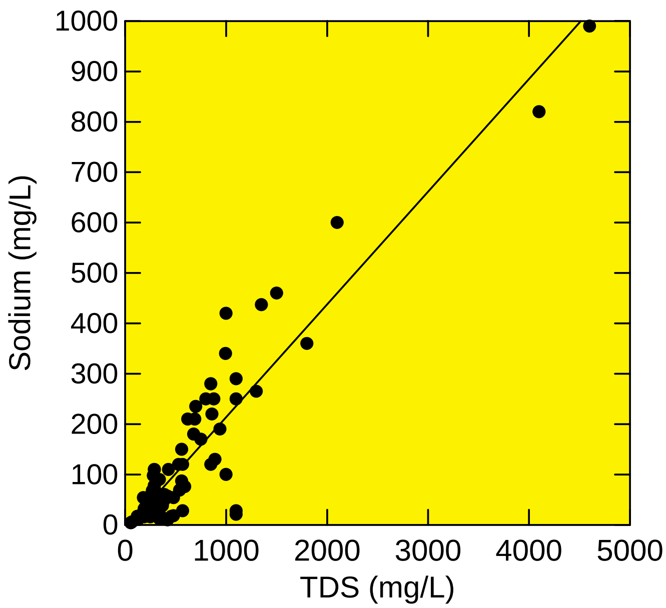


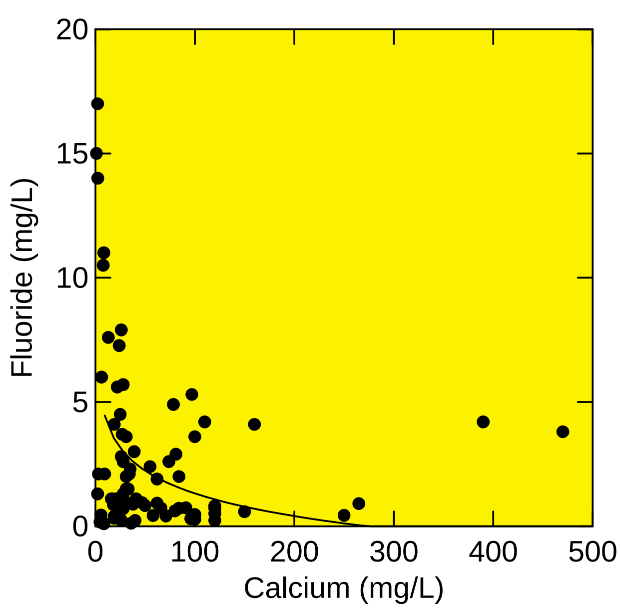
Table 6. Correlations Among Groundwater Quality Constituent Concentrations Using Pearson Probabilities

Constituent	Significant Positive Relationship, p=0.01	Significant Positive Relationship, p=0.05	Significant Negative Relationship, p=0.01	Significant Negative Relationship, p=0.05
Temperature (T)	SC, TDS, Cl, Na, K, As, B, β	F	-	-
pH - field	pH-lab, CO_3	α	-	Ca, Hard
pH - lab	pH-f, CO_3	α, β	-	D
SC - field	T, TDS, Cl, SO_4, Na, K, As, B	β	-	-
TDS	T, SC, Cl, SO_4, Na, As, B	K	-	-
Turbidity	TKN, P, Fe	-	-	-
Total Alkalinity	HCO_3	Mg	-	-
Bicarbonate (HCO_3)	TAlk	Mg	-	-
Carbonate (CO_3)	pH-f, pH-lab, α	-	O, D	-
Chloride (Cl)	T, SC, TDS, Na, K, B, β	As	-	-
Sulfate (SO_4)	SC, TDS, Ca	Hard	-	-
Calcium (Ca)	SO_4, Hard	Mg	-	pH-f
Magnesium (Mg)	HCO_3 , Hard	TAlk	-	-
Hardness	Ca, Mg	SO_4, D		pH-f
Sodium (Na)	T, SC, TDS, Cl, K, As, B, β	F	-	-
Potassium (K)	T, SC, Cl, Na, B, β	TDS, As	-	-
Fluoride (F)	B	T, Cl, Na, As	-	-
Nitrate (NO_3)	-	-	-	-
Arsenic (As)	T, SC, Na, B	TDS, Cl, K, F	-	-
Boron (B)	T, SC, TDS, Cl, Na, K, F, As, β	-	-	-
Zinc (Zn)	-	-	-	-
Gross Alpha (α)	CO_3	pH-f, pH-lab	-	-
Gross Beta (β)	T, Cl, Na, K, B	pH-lab, SC	-	D
Oxygen (O)	D	Mg	CO_3	-
Deuterium (D)	Mg, O	Hard	CO_3	pH-lab, β

Figure 15. Sodium - TDS and Fluoride - Calcium Concentration Covariation



Among SS sample sites, TDS concentrations are best predicted among major ions and cations by sodium concentrations (multiple regression analysis, $p \leq 0.01$, $y = 3.84x + 128$, $n = 77$, $r = 0.92$). Although recharge areas usually contain low concentrations of sodium, it's frequently the dominant cation in downgradient areas.[20] TDS concentrations are greatest in the northern portions of the sub-basin. The elevated TDS concentrations are related to increasing sodium concentrations from silicate weathering and halite dissolution along with ion exchange.[28]



This graph illustrates the negative exponential relationship between fluoride and calcium at sites in the San Simon sub-basin (Pearson correlation coefficient test, $p \leq 0.01$, $y = -1.3x + 7.4$, $n = 77$, $r = 0.46$). These findings support previous assertions that there are multiple controls on fluoride concentrations.[28] Calcium appears to be an important control on the highest fluoride concentrations (>5 mg/L) though precipitation of the mineral fluorite. High concentrations of fluoride had corresponding depleted concentrations of calcium. Previous studies have cited hydroxyl ion exchange or sorption-desorption reactions at providing controls on lower (< 5 mg/L) fluoride concentrations.

Aquifer Constituent Co-variation

Alluvial Aquifer - Sample sites in the *alluvial aquifer* reflected the relative uniformity of this water-bearing unit with strong positive correlations among TDS, SC, hardness, major ions (calcium, magnesium, sodium, chloride, and sulfate), and nitrate (Pearson Correlation Coefficient test, $p \leq 0.05$). Other patterns of interest include positive correlations among pH-lab, pH-field, bicarbonate, and fluoride as well as among temperature, potassium, and bicarbonate.

TDS concentrations are best predicted among cations equally by calcium, sodium and magnesium concentrations while among anions, sulfate is the best predictor (multiple regression analysis, $p \leq 0.01$).

Bedrock - Sample sites in *bedrock* areas exhibited the highest degree of significant correlations and the most interesting patterns. TDS and SC were positively correlated with major ions (calcium, magnesium, sodium, bicarbonate, chloride, and sulfate) as well as with temperature, pH-lab, hardness, boron, and fluoride (Pearson Correlation Coefficient test, $p \leq 0.05$). However, this pattern bifurcated depending on whether the dominant cation was calcium or sodium. Calcium was inter-correlated with hardness, magnesium, bicarbonate, and sulfate. In contrast sodium was inter-correlated with potassium, bicarbonate, chloride, nitrate, arsenic, boron, and fluoride. Perhaps the most interesting bedrock correlation was between nitrate and both oxygen-18 and deuterium; this indicates that higher nitrate concentrations are more likely to be from recently recharged water.

TDS concentrations are best predicted among cations by calcium concentrations while among anions, sulfate is the best predictor (multiple regression analysis, $p \leq 0.01$).

Lower Aquifer - Sample sites in the *lower aquifer* had relatively few significant correlations. Positive correlations occurred among TDS, SC, temperature, sodium, and sulfate (Pearson Correlation Coefficient test, $p \leq 0.05$). Fluoride concentrations from samples collected from the lower aquifer are often elevated over water quality standards. This constituent has important correlations with both pH-field (positive) and calcium (negative).

TDS concentrations are best predicted among cations by sodium concentrations while among anions, sulfate and chloride are almost equally the best predictor (multiple regression analysis, $p \leq 0.01$).

Upper Aquifer - Sample sites in the *upper aquifer* had the common significant positive correlations among TDS, SC, hardness, major ions (calcium, magnesium, sodium, potassium, chloride, and sulfate) and nitrate (Pearson Correlation Coefficient test, $p \leq 0.05$). Of particular interest is the TDS-nitrate relationship which may indicate that the poor quality, salt-laden irrigation water that recharges the upper aquifer also frequently carries with it nitrate.

TDS levels are best predicted among cations by sodium concentrations while among anions, sulfate is the best predictor (multiple regression analysis, $p \leq 0.01$).

GROUNDWATER QUALITY PATTERNS

Spatial Variation

Groundwater in the SS was characterized by assessing the spatial variation of groundwater quality among water-bearing units and rock types.

Aquifer Comparison – In a very simplified model, the SS can be divided into four water-bearing units: the *alluvial aquifer,* the *upper aquifer,* the *lower aquifer,* and mountain *bedrock.* Analytical results were compared between these four water-bearing units to identify significant differences in concentrations of groundwater quality constituents. Many significant differences were found, such as with TDS, illustrated in Figure 16. The results are provided in Table 7 (ANOVA test with Tukey option, $p \leq 0.05$). The 95% confidence intervals for constituent concentrations for each SS water-bearing unit found to be significantly different are in Table 8.

Aquifer-Watershed Comparison – In another very simplified model, the SS can be further divided into seven hydrologic units for comparison purposes by subdividing the mountain bedrock into four ranges: Chiricahua, Dos Cabezas, Peloncillo and Pinaleno. Analytical results were compared between these seven hydrologic units to identify significant differences in concentrations of groundwater quality constituents. Many significant differences were found and are listed in Table 9 (ANOVA test with Tukey option, $p \leq 0.05$). The 95% confidence intervals for constituent concentrations for each SS water-bearing unit found to be significantly different are in Table 10.

Geological Comparison - The SS can be divided into five geologic classifications: alluvium, basaltic, granite, sedimentary, and volcanic (Map 2).[26] Analytical results were examined for differences in concentrations of groundwater quality constituents among the five geologic classifications. Many significant patterns were revealed with this geological comparison, such as with gross alpha (Figure 16). Data are provided in Table 11 (ANOVA test with the Tukey test, $p \leq 0.05$). The 95% confidence intervals for constituent concentrations for each SS water-bearing unit found to be significantly different are in Table 12.

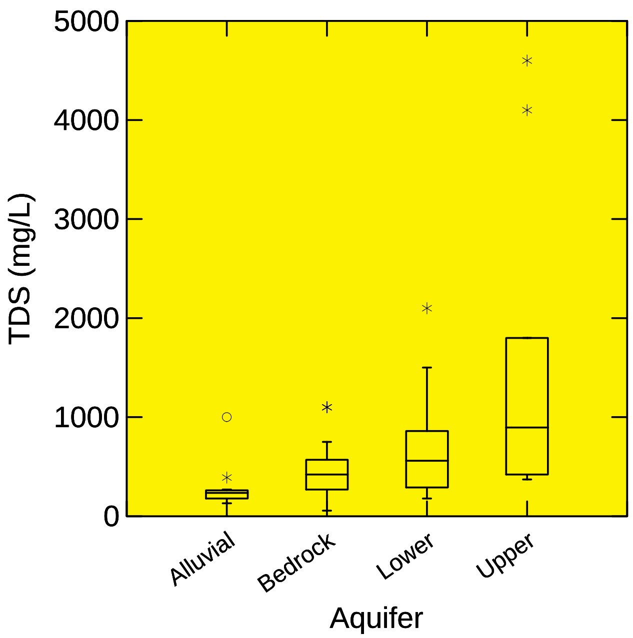
Constituent Covariation with Groundwater Depth

The constituent concentrations of the sample sites were compared to the corresponding groundwater depth for each SS sample site. Depth was determined using a sounder in the field or data from ADWR well registration records. Comparisons were made using three distinct methods: a linear model, an exponential model, and a biphasic model. The linear model compares constituent concentrations to groundwater depth, the exponential model compares the log-transformed constituent concentrations to groundwater depth, and the biphasic model compares the log-transformed constituent concentrations to log-transformed groundwater depth. The overall results indicate that 9 of the 27 groundwater quality constituents examined had one or more mathematical equations significantly relating constituent concentrations to groundwater depth (regression analysis, $p \leq 0.05$). Of these significant relationships, most constituents (TDS, SC, bicarbonate, sodium, sulfate, fluoride, boron, and zinc) had concentrations decreasing with increasing groundwater depth below land surface (bls). In contrast, only temperature increased with increasing groundwater depth bls. Patterns involving groundwater depth and constituent concentrations were also examined for the *alluvial aquifer*. Of the 27 groundwater quality constituents examined, four (temperature, bicarbonate, potassium, and oxygen-18) significantly increased with increasing groundwater depth (regression analysis, $p \leq 0.05$).

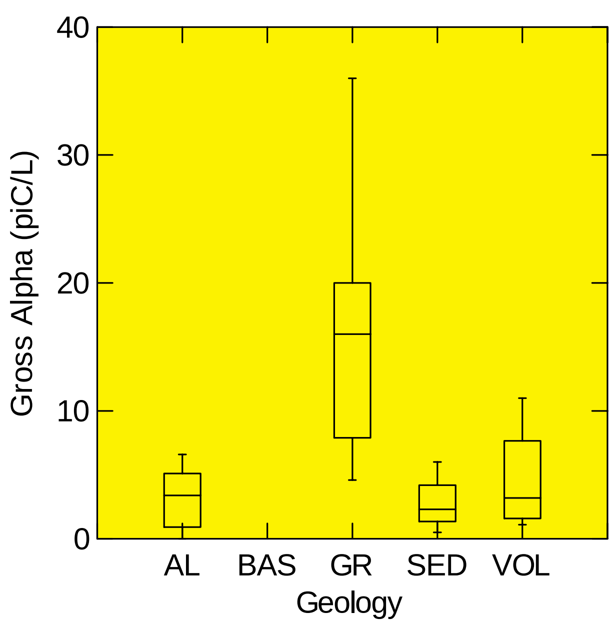
Constituent Co-variation with Well Depth

The constituent concentrations of the sample sites were compared to the corresponding well depth for each SS sample site. Depth was determined using data from ADWR well registration records. As with groundwater depth, comparisons were made using three distinct methods: a linear model, an exponential model, and a biphasic model. The overall results indicate that 13 of the 27 groundwater quality constituents examined had one or more mathematical equations significantly relating constituent concentrations to groundwater depth (regression analysis, $p \leq 0.05$). Of these significant relationships, most constituents (TDS, SC, bicarbonate, calcium, magnesium, hardness, sulfate, fluoride, nitrate, and arsenic) had concentrations decreasing with increasing well depth bls. In contrast, only temperature, pH-field, and pH-lab increased with increasing well depth bls.

Figure 16. TDS and Gross Alpha Concentrations Relative to Aquifers and Geology



This boxplot illustrates the variation in total dissolved solids (TDS) concentrations between four SS water-bearing units. TDS concentrations are highest in the upper aquifer and decrease respectively in the lower aquifer, bedrock, and alluvial aquifer. However, statistics indicate that some of these differences may be by chance. Significant differences only occur with higher concentrations in the upper aquifer compared to the bedrock or alluvial aquifer and the lower aquifer compared to the alluvial aquifer (ANOVA with Tukey test, $p \leq 0.01$). These TDS patterns appear to be the result of recharge sources and dissolution reactions as groundwater moves downgradient [28]



This boxplot illustrates the variation in gross alpha concentrations between five SS water-bearing units. Radiochemistry samples were collected at 23 of the 77 sites. The highest gross alpha concentrations, often over the health-based standard of 15 pCi/L, are found in sites located in granite (GR) geology.[34] Statistical tests indicate that gross alpha concentrations in granite geology are significantly higher than those in either alluvial (AL) or sedimentary (SED) geology (ANOVA with Tukey test, $p \leq 0.05$). Previous studies indicate radiochemistry concentrations are generally higher in low-yield wells located in granite.[23] In the San Simon sub-basin, granite rock generally occurs in the Dos Cabezas and Pinaleno Mountains.[26]

Table 7. Variation in Groundwater Quality Constituent Concentrations Among Four SS Water-Bearing Units Using Transformed Data with the ANOVA and Tukey Tests

Constituent	Significance	Water-Bearing Unit Significant Differences
Oxygen-18	**	Lower > Upper, Alluvial & Bedrock
Deuterium	**	Lower > Upper, Alluvial & Bedrock
Temperature - f	**	Lower > Upper & Bedrock
pH - f	**	Lower > Bedrock; Lower & Alluvial > Upper
pH - lab	**	Lower > Upper, Alluvial & Bedrock
SC - f	**	Upper > Alluvial & Bedrock; Lower > Alluvial
SC - lab	**	Upper > Alluvial & Bedrock; Lower > Alluvial
Turbidity	*	Bedrock > Alluvial
TDS	**	Upper > Alluvial & Bedrock; Lower > Alluvial
Bicarbonate	ns	
Calcium	**	Upper > Lower
Magnesium	**	Upper & Bedrock > Lower
Hardness	**	Upper > Lower & Alluvial
Sodium	**	Upper & Lower > Alluvial & Bedrock
Potassium	**	Upper & Lower & Alluvial > Bedrock
Chloride	**	Upper & Lower > Alluvial & Bedrock
Sulfate	**	Upper & Lower > Alluvial & Bedrock
Fluoride	**	Upper & Lower > Bedrock
Nitrate (as N)	**	Upper > Lower
TKN	ns	
Total Phosphorus	**	Alluvial & Bedrock > Lower
Boron	**	Upper & Lower > Alluvial & Bedrock
Arsenic	**	Lower > Alluvial & Bedrock
Iron	ns	
Zinc	ns	
Gross alpha	ns	
Radon	ns	

ns = not significant   * = significant at $p \leq 0.05$ ** = significant at $p \leq 0.01$

Table 8. Summary Statistics (95% Confidence Intervals) for Groundwater Quality Constituents With Significant Concentration Differences Among Four SS Water Bearing Units

Constituent	Significant Differences	Alluvial	Bedrock	Lower Aquifer	Upper Aquifer
Oxygen-18	**	-9.6 to -10.1	-9.5 to -10.4	-10.2 to -11.2	-8.4 to 9.6
Deuterium	**	-67 to -71	-67 to -73	-74 to -81	-59 to -71
Temperature - f	**	23.3 to 26.9	21.0 to 25.4	26.4 to 30.2	20.9 to 23.4
pH - f	**	7.74 to 8.00	7.38 to 7.75	7.88 to 8.30	7.11 to 7.62
pH - lab	**	7.43 to 7.68	7.12 to 7.55	7.93 to 8.32	7.27 to 7.95
SC - f	**	219 to 590	493 to 851	754 to 1286	657 to 3495
SC - lab	**	228 to 610	507 to 873	772 to 1317	677 to 3601
Turbidity	*	-0.3 to 1.7	-0.8 to 15.7	-	-
TDS	**	147 to 420	327 to 573	503 to 848	401 to 2881
Bicarbonate	ns	-	-	-	-
Calcium	**	21 to 63	43 to 95	22 to 49	28 to 279
Magnesium	**	1.3 to 11.3	8.8 to 17.2	2.8 to 8.7	8.8 to 42.9
Hardness	**	55 to 201	153 to 314	73 to 164	114 to 799
Sodium	**	22 to 50	34 - 88	126 to 241	80 to 605
Potassium	**	2.0 to 4.7	0.9 to 2.4	3.4 to 6.6	1.9 to 8.5
Chloride	**	-1 to 29	10 to 56	46 to 133	17 to 208
Sulfate	**	-13 to 136	62 to 190	133 to 250	30 to 1516
Fluoride	**	0.8 to 2.2	0.70 to 1.60	2.9 to 6.6	1.3 to 5.0
Nitrate (as N)	**	-	-	0.4 to 1.7	1.1 to 20.6
TKN	ns	-	-	-	-
T. Phosphorus	**	-.035 to 0.133	0.023 to 0.066	0.007 to 0.025	-
Boron	**	0.005 to 0.005	0.016 to 0.101	0.06 to 0.64	0.02 to 0.79
Arsenic	**	0.005 to 0.005	0.005 to 0.008	0.002 to 0.085	-
Iron	ns		-	-	-
Zinc	ns		-	-	-
Gross alpha	ns		-	-	-
Radon	ns		-	-	-

Table 9. Variation in Groundwater Quality Constituent Concentrations Among Seven SS Water-Bearing Units Using Transformed Data with the ANOVA and Tukey Tests

Constituent	Significance	Water-Bearing Unit Significant Differences
Oxygen-18	**	Alluvial > Lower; Upper > Dos Cab, Lower & Pina; Pel > Alluvial, Chir, Dos Cab, Lower & Pina
Deuterium	**	Chir, Dos Cab, Lower, Pel & Upper > Lower; Chir, Pen & Upper > Pina
Temperature - f	**	Alluvial, Lower & Pinaleno > Chiricahua; Lower > Upper
pH – f	**	Lower > Chiricahua, Dos Cabezas & Upper
pH – lab	**	Alluvial, Lower & Upper > Chir; Lower > Alluvial, Dos Cab, Pel & Upper
SC – f	**	Upper & Lower > Alluvial & Chiricahua
SC – lab	**	Upper & Lower > Alluvial & Chiricahua
Turbidity	ns	
TDS	**	Upper & Lower > Chiricahua & Alluvial; Upper > Pinaleno
Bicarbonate	**	Dos Cabezas, Lower, Peloncillo, Pinaleno & Upper > Chiricahua
Calcium	**	Upper & Dos Cabezas > Lower
Magnesium	**	Upper & Dos Cabezas > Lower
Hardness	**	Upper & Dos Cabezas > Lower
Sodium	**	Upper & Lower > Alluvial, Chir & Dos Cab; Pel & Pina > Chir
Potassium	**	Upper & Lower > Chir, Dos Cab & Pina; Alluvial > Dos Cab Pina
Chloride	**	Upper & Lower > Alluvial & Chir; Dos Cab & Pel > Chir
Sulfate	**	Upper & Lower > Alluvial & Pina; Upper > Chir; Dos Cab > Alluvial
Fluoride	**	Upper & Lower > Chiricahua; Lower > Dos Cabezas
Nitrate (as N)	**	Upper > Chiricahua & Lower
TKN	ns	
Total Phosphorus	**	Alluvial, Chiricahua & Dos Cabezas > Lower
Boron	**	Upper & Lower > Alluvial & Chiricahua; Lower > Dos Cabezas
Arsenic	**	Lower > Alluvial
Iron	**	Dos Cabezas > Alluvial, Chiricahua, Lower & Upper
Zinc	ns	
Gross alpha	ns	
Radon	ns	

ns = not significant * = significant at $p \leq 0.05$ ** = significant at $p \leq 0.01$

Table 10. Summary Statistics (95% Confidence Intervals) for Groundwater Quality Constituents With Significant Concentration Differences Among Seven SS Water Bearing Units

Constituent	Alluvial Aquifer	Chiricahua	Dos Cabezas	Lower Aquifer	Pelconcillo	Pinaleno	Upper Aquifer
Oxygen-18	-9.6/10.1	-9.5/10.3	-9.7/10.7	-10.3/11.2	-6.6/-9.9	-9.5/11.8	-8.6/9.6
Deuterium	-67.2/70.8	-64.7/69.5	-67.5/74.2	-75.8/81.7	-51.9/73.7	-67.1/84.6	-60.1/69.3
Temperature - f	23.3-26.9	114.7-24.3	-	26.3-30.2	-	20.7-35.8	21.0-24.3
pH - f	-	7.08-7.92	7.20-7.62	7.92-8.32	-	-	7.13-7.58
pH - lab	7.43-7.68	6.54-7.24	7.22-7.71	7.98-8.33	6.53-8.37	-	7.24-7.88
SC - f	219-590	70-998	-	779-1310	-	-	650-3220
SC - lab	228-610	75-1027	-	797-1341	-	-	673-3319
TDS	147-420	42-792	-	517-862	-	109-511	406-2644
Bicarbonate	-	35-235	223-368	150-248	114-382	94-350	207-372
Calcium	-	-	61-105	20-46	-	-	35-258
Magnesium	-	-	10-26	3-9	-	-	8-39
Hardness	-	-	207-369	70-159	-	-	126-738
Sodium	22-50	7-22	6-135	133-247	33-128	21-105	74-553
Potassium	2.0-4.7	0.9-1.6	0.6-1.7	3.6-6.9	-	-0.1-2.4	2.1-8.0
Chloride	-1-29	2-6	-16-120	50-137	-22 - 169	-	20-191
Sulfate	-13-136	-34-416	69-181	136-253	-	-38-108	47-1379
Fluoride	-	0.2-0.7	0.2-2.3	3.0-6.7	-	-	1.2-4.6
Nitrate (as N)	-	0.1-0.6	-	0.4-1.6	-	-	1.3-18.8
T. Phosphorus	-.035-.133	.002-.113	-.009-.124	.008-.024	-	-	-
Boron	.005-.005	.005-.005	-.027-.128	.078-.649	-	-	.017-.713
Arsenic	.005-.005	-	-	.003-.085	-	-	-
Iron	.032-.099	0.05-0.05	-.394-2.437	.042-.113	-	-	.049-.053
Zinc	-	-	-	-	-	-	-
Gross alpha	-	-	-	-	-	-	-
Radon	-	-	-	-	-	-	-

Table 11. Variation in Groundwater Quality Constituent Concentrations Among Five SS Geologic Units Using Transformed Data with the ANOVA and Tukey Tests

Constituent	Significance	Geologic Unit Significant Differences
Oxygen-18	ns	
Deuterium	ns	
Temperature - f	**	Alluvial & Granite > Volcanic
pH - f	ns	
pH - lab	**	Alluvial > Volcanic
SC - f	ns	
SC - lab	ns	
Turbidity	ns	
TDS	ns	
Bicarbonate	**	Granite > Volcanic
Calcium	*	Sedimentary > Alluvial & Volcanic
Magnesium	ns	
Hardness	**	Sedimentary > Alluvial & Granite & Volcanic
Sodium	*	Alluvial > Sedimentary
Potassium	**	Alluvial > Granite & Sedimentary; Basaltic > Granite
Chloride	ns	
Sulfate	ns	
Fluoride	**	Alluvial > Volcanic
Nitrate (as N)	ns	
TKN	ns	
Total Phosphorus	ns	
Boron	ns	
Arsenic	ns	
Zinc	ns	
Gross alpha	*	Granite > Alluvial & Sedimentary
Gross beta	ns	
Radon gas	ns	

ns = not significant * = significant at $p \leq 0.05$ ** = significant at $p \leq 0.01$

Table 12. Summary Statistics (95% Confidence Intervals) for Groundwater Quality Constituents With Significant Concentration Differences Among Five SS Geologic Units

Constituent	Significant Differences	Alluvial	Basaltic	Granite	Sedimentary	Volcanic
Oxygen-18	ns					
Deuterium	ns					
Temperature - f	**	25.1 - 27.7		21.3 - 32.4		15.8 - 24.6
pH – f	ns					
pH – lab	**	7.69 – 7.99				6.72 - 7.71
SC – f	ns					
SC – lab	ns					
Turbidity	ns					
TDS	ns					
Bicarbonate	**			239 - 401		85 - 243
Calcium	*	33 - 80			65 - 239	13 - 46
Magnesium	ns					
Hardness	**	109 - 251		211 - 397	221 - 697	47 - 158
Sodium	**	111 - 224			13 - 25	
Potassium	**	3.2 - 5.2	8.4 - 8.4	0.5 - 1.3	0.6 – 1.7	
Chloride	ns					
Sulfate	ns					
Fluoride	**	2.4 - 4.6				0.3 – 2.0
Nitrate (as N)	ns					
TKN	ns					
T. Phosphorus	ns					
Boron	ns					
Arsenic	ns					
Iron	ns					
Zinc	ns					
Gross alpha	*	1.7 - 4.9		1.6 - 32.2	-0.9 – 6.5	
Gross beta	ns					
Radon	ns					

ns = not significant   * = significant at $p \leq 0.05$ ** = significant at $p \leq 0.01$

Isotope Comparison - Groundwater characterizations using oxygen and hydrogen isotope data may be made with respect to the climate and/or elevation where the water originated, residence within the aquifer, and whether or not the water was exposed to extensive evaporation prior to collection.[11] These characterizations are made by comparing oxygen-18 isotopes ($\delta^{18}O$) and deuterium (δD), an isotope of hydrogen, data to the Global Meteoric Water Line (GMWL). The GMWL is described by the linear equation: $\delta D = 8\delta^{18}O + 10$ where δD is deuterium in parts per thousand (per mil, $^0/_{00}$), 8 is the slope of the line, $\delta^{18}O$ is oxygen-18 $^0/_{00}$, and 10 is the y-intercept.[11] The GMWL is the standard by which water samples are compared and represents the best fit isotopic analysis of numerous water samples, worldwide.

Regional isotopic data may be plotted to create a Local Meteoric Water Line (LMWL) which is affected by varying climatic and geographic factors. When the LMWL is compared to the GMWL, inferences may be made about the origin or history of the local water.[11] The LMWL created by $\delta^{18}O$ and δD values for samples collected at sites in the SS were compared to the GMWL. The δD and $\delta^{18}O$ data lie to the right of the GMWL (Figure 17). Meteoric waters exposed to evaporation characteristically plot increasingly below and to the right of the GMWL. Evaporation tends to preferentially contain a higher percentage of lighter isotopes in the vapor phase; the water that remains behind is isotopically heavier.[11]

Groundwater from arid environments is typically subject to evaporation which enriches δD and $\delta^{18}O$ resulting in a lower slope value (usually between 3 and 6) as compared to the slope of 8 associated with the GMWL.[11] The data for the arid SS conform to this theory, having a slope of 6.51, with the LMWL described by the linear equation:

$$\delta D = 6.51^{18}O - 6.09$$

The most depleted or isotopically lighter waters are generally associated with sites in the *lower aquifer* or *bedrock* near the Pinaleno Mountains. Significant differences were found in the δD and $\delta^{18}O$ in *lower aquifer* sites compared with sites in the *alluvial aquifer*, *bedrock*, or the *upper aquifer* (ANOVA test with Tukey option, $p \leq 0.05$). Some of these sites appear to represent the oldest water in the sub-basin, recharged during a time period cooler than present. Higher on the evaporation trajectory are intermixed sites from the *alluvial aquifer, bedrock,* and *upper aquifer*. All these sites appear to be predominantly recharged from local winter precipitation with increasing amounts of summer monsoon recharge as the sites plot further up the evaporation trajectory.[41] No significant differences were found in the δD and $\delta^{18}O$ in among these three water-bearing units (ANOVA test with Tukey option, $p \leq 0.05$). However, sites in or near the Dos Cabezas Mountains tend to be the most depleted, followed by those in the *alluvial aquifer*, and sites in or near the Chiricahua Mountains. The surface water sample collected from Cave Creek in the Chiricahua Mountains above the town of Portal was also in this group. Sites in or near the Peloncillo Mountains and in the *upper aquifer* tend to be the most enriched.

The most enriched sites at the top of the evaporation trajectory consisted of two windmills located on the fringes of the Peloncillo Mountains and a very shallow windmill located along the San Simon River downgradient of the town of San Simon. These sites are probably predominantly recharged from summer monsoon storms.[41]

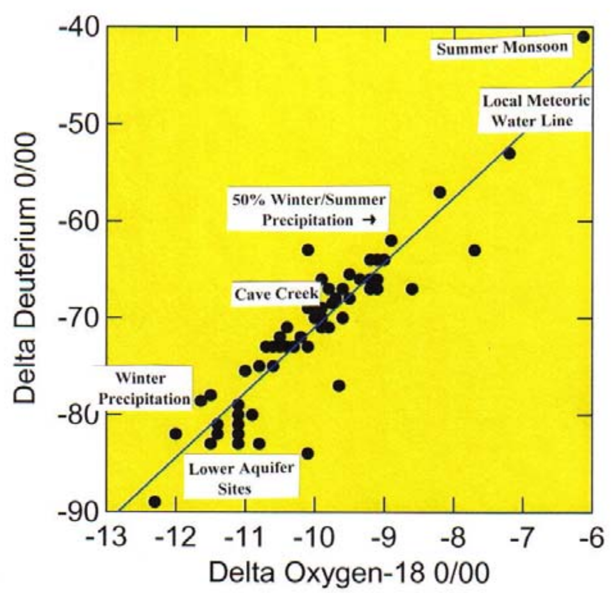


Figure 17. Values for 63 isotope samples are shown in this graph. Most sites in the bedrock, alluvial aquifer, and upper aquifer are clustered in the center of the graph with more depleted lower aquifer sites in the lower left corner. Lower aquifer isotope sites were found to be significantly different from bedrock, alluvial aquifer, and upper aquifer sites (ANOVA test with Tukey option, $p \leq 0.01$).

CONCLUSIONS

Groundwater Suitability for Domestic Use

Groundwater in the SS is generally suitable for domestic and/or municipal use with 67 percent of sample sites (52 of 77) meeting all health-based water quality standards. The 25 sites that did not meet health-based standards are mostly clustered around the town of San Simon and generally follow the San Simon River northwest to the sub-basin boundary. Thus, sites representing large areas of the SS, particularly in the southern but also in the western portions, met all health based standards. The 29 sample sites that also met all aesthetics-based standards also follow the same geographic pattern.

Overall Groundwater Quality

The San Simon sub-basin of the Safford Groundwater Basin is large and hydrologically complex. Groundwater quality varies dramatically within the sub-basin but some general patterns may be discerned.

Calcium concentrations are best predicted among anions by sulfate concentrations; in contrast, sodium concentrations are best predicted almost equally by sulfate and chloride concentrations with carbonate concentrations also having a major influence (multiple regression, $p \leq 0.01$). The calcium - sulfate relationship may be impacted by the dissolution of calcite and gypsum concentrated by evaporation during irrigation of agricultural areas that subsequently recharges the groundwater.[10] In contrast, the sodium - chloride/sulfate relationship may be related to the dissolution of evaporite deposits.[20 28] Geophysical studies and drilling data indicate that the San Simon Valley contains significant quantities salt and gypsum deposits, that are over 2,700 feet thick at Tanque.[4, 44]

Many constituents significantly decreased with increasing groundwater and/or well depth (regression, $p \leq 0.05$). However, groundwater and/or well depth were often unable to be determined. Groundwater depth data were further complicated by levels representing artesian or partial artesian flows rather than water table conditions. Thus, water level in a well tapping the *lower aquifer* could be shallower than a well tapping the *upper aquifer*. As such, these correlations are of limited value and should be cautiously interpreted and used.
The SS is perhaps better described by examining groundwater evolution from the southern upgradient areas to northern downgradient areas with Interstate 10 roughly the dividing line.

San Simon sub-basin south of Interstate 10 - The southern portion of the SS consists of bedrock of the Chiricahua Mountains, the Dos Cabezas Mountains, and the unconfined *alluvial aquifer* which occupies the valley areas between the Chiricahua Mountains and the New Mexico border. This area might be roughly considered all of the sub-basin south of Interstate 10 with the exception of irrigated areas in the vicinity of the town of San Simon.

The groundwater in these areas is generally suitable for domestic and/or municipal use; only three sample sites exceeded health based water quality standards. Two sites in the Dos Cabezas had gross alpha exceedances and a fluoride exceedance occurred near the New Mexico town of Rodeo. In addition, most samples also met aesthetics based water quality standards in these areas. Exceedances occurred with TDS and sulfate at two sites in the Chiricahuas, fluoride at two sites in the *alluvial aquifer*, and at six sites in the Dos Cabezas involving various combinations of TDS, chloride, fluoride, iron, and manganese.

Most sample sites in this area had a calcium-bicarbonate chemistry which often is indicative of recharge areas.[28] Bicarbonate was the predominant anion except at two sulfate sites in the Chiricahuas. This area generally had the freshest groundwater in the sub-basin with TDS aesthetic based standards of 500 mg/L rarely exceeded and often below 250 mg/L. The two sites with TDS exceedances in the Chiricahuas also had sulfate aesthetics based standard exceedances likely indicating that these sites are impacted by nearby historic mining operations.[21] TDS concentrations in the Dos Cabezas tended to be slightly higher than in the Chiricahuas or the *alluvial aquifer*.

Constituents, such as arsenic and nitrate, which commonly exceed health-based water quality standards in groundwater in Arizona, were low in the southern portion of the sub-basin. The majority of fluoride concentrations were also low except in three locations: the extreme southern portion of the *alluvial aquifer*; the northeast portion of the alluvial aquifer along the New Mexico state line; and the western portion of the Dos Cabezas range.

San Simon sub-basin north of Interstate 10 - The northern portion of the SS consists of the *upper aquifer*, the *lower aquifer*, and *bedrock* of the Peloncillo Mountains and the Pinaleno Mountains.

This area might be roughly considered all the sub-basin north of Interstate 10 in addition to the irrigated areas south of the freeway near the town of San Simon.

The groundwater in this area commonly is unsuitable for domestic and/or municipal use without additional water treatment. Sample sites in or near the Peloncillo Mountains, the Pinaleno Mountains, and near the town of Bowie generally met all health based water quality standards. However, the majority of sample sites around the town of San Simon and northwest along the San Simon River exceeded both health based and aesthetics based water quality standards.

Most sample sites in the northern portions of the sub-basin had either a sodium-bicarbonate or sodium-mixed chemistry. These chemistries, along with higher pH values, are common in downgradient areas.[28] Previous studies had found sodium percentages greater than 75 in the northwestern part of the sub-basin.[15] In downgradient areas, sodium often becomes the dominant cation probably as the result of halite dissolution.[28] Very few sites had a calcium or mixed predominant cation. The predominant anion was either bicarbonate or mixed except for sulfate at some sites around and downgradient of the town of San Simon.

The freshest groundwater in the northern portion of the sub-basin generally was found at sites west of the town of Bowie (including the Pinaleno Mountains) and near the town of San Simon and the Peloncillo Mountains. These sites had TDS concentrations generally below the aesthetic based standard of 500 mg/L. Northwest of the town of San Simon along the San Simon River, sites mostly exceeded TDS standards with some slightly saline with concentrations over 1,000 mg/L.[18]

Fluoride and arsenic concentrations commonly exceeded health-based water quality standards in the southern portion of the sub-basin. Fluoride exceedances generally occurred around and northwest of the town of San Simon. In contrast, arsenic exceedances generally occurred only northwest of the town of San Simon. Nitrate was also elevated at a few sites around the town of San Simon, which is probably due to nitrogen fertilizer applications applied to irrigated farmland and subsequently recharged to groundwater.[10] Nitrate was also elevated at an isolated shallow windmill northwest of the town of Bowie. This is likely the result of a nearby livestock corrals where cattle frequently water. Other likely occurrences of cattle impacting shallow windmills in remote locations have been noted in the Douglas, Sacramento Valley, and Detrital Valley groundwater basins.

Aquifer Overview

Alluvial Aquifer – This unconfined aquifer is used only for the purposes of this report and is defined as the alluvial areas south of the San Simon Cienega. The demarcation of the *alluvial aquifer* is based on observed and often dramatic water chemistry changes that occur between the San Simon Cienega and the town of San Simon. The *alluvial aquifer* has few water quality exceedances and the lowest salinity concentrations in the sub-basin. The only health based water quality exceedance was fluoride at one site near Rodeo. Fluoride exceedances in the Rodeo area were also reported in previous studies.[6]

In the *alluvial aquifer*, fluoride concentrations are positively correlated with pH-field levels (Pearson Correlation Coefficient test, $p \leq 0.01$). This correlation suggests that exchange of hydroxyl ions for fluoride may be occurring and probably is a control, perhaps the most important, of fluoride concentrations in solution.[29] During weathering of fluoride-containing rocks, particularly schist and volcanic rocks, the fluoride ions may initially exchange for hydroxyl groups on clays. This process would be favored by the lower, near neutral pH conditions of recharge areas and by the electronegativity of fluoride and identical size of fluoride and hydroxyl ions. As pH values increase downgradient through silicate hydrolysis reactions, greater concentrations of hydroxyl ions may increase the concentrations of fluoride in solution.[28]

Groundwater sampled in the *alluvial aquifer* is significantly heavier or enriched (and appear to consist of more recent recharge) than groundwater in the *lower aquifer* based on oxygen-18 and deuterium isotope levels. Groundwater sampled in the *alluvial aquifer* had significantly lower concentrations of TDS, sodium, chloride, sulfate, boron, arsenic, and pH values than sites in the *lower aquifer*. Except for pH-lab and arsenic, this pattern is repeated for the *upper aquifer* (ANOVA with Tukey test, $p \leq 0.05$).

Upper Aquifer - Defined in this report as the unconfined aquifer located in alluvial areas north of the San Simon Cienega, the *upper aquifer* commonly has water quality exceedances of fluoride and nitrate (health based) and TDS and sulfate (aesthetics based). Elevated fluoride concentrations in the *upper aquifer* are likely the result of upward leakage of high-fluoride water from the *lower aquifer*.[28] TDS levels may be elevated to the extent that groundwater is considered slightly saline.[18] In the *upper aquifer*, TDS and nitrate concentrations are positively correlated (Pearson Correlation Coefficient test, $p \leq 0.05$). This relationship is a strong indication that salt-laden irrigation water carrying nitrates is recharging the *upper aquifer*, a phenomena that appears to be also occurring in the nearby Willcox groundwater basin.[10 33]

Groundwater sampled in the *upper aquifer* is significantly heavier or enriched (and probably consists of more recent recharge) than those in the *lower aquifer* based on oxygen-18 and deuterium isotope levels. Groundwater samples in the *upper aquifer* have significantly lower temperature, pH-field, and pH-lab levels than the *lower aquifer*. This pattern is reversed with calcium, magnesium, hardness, and nitrate concentrations. Previous studies had cited the more highly mineralized waters of non-artesian waters compared with artesian water.[15] In addition, groundwater samples in the *upper aquifer* had higher concentrations of TDS, sodium, chloride, sulfate, boron and fluoride (*bedrock* only) than groundwater samples from the *bedrock or* the *alluvial aquifer* (ANOVA with Tukey test, $p \leq 0.05$).

Many of these patterns can be explained by agricultural activities that impact recharge to the *upper aquifer*. Elevated nitrate concentrations are likely the result of nitrogen fertilizer applied to irrigated fields.[10] The major source of elevated calcium, hardness, and TDS concentrations is the dissolution of calcite and salts concentrated by evaporation during irrigation, than recharged to the aquifer.[10] Thus, the *upper aquifer* appears to be a *chemically open system* or one in which the aquifer chemistry is controlled or influenced by gases or water that enter the system after the initial recharge.[28]

Lower Aquifer - Defined in this report as the confined or partially confined aquifer located in alluvial areas north of the San Simon Cienega, the *lower aquifer* often has water quality exceedances of fluoride and arsenic (health based) and TDS, sulfate, and pH (aesthetics based). TDS concentrations may, in places, be elevated to the extent that groundwater is considered *slightly saline*.[18] The *lower aquifer* is likely a *chemically closed system*, or one in which the aqueous chemistry is determined solely by the reactions of the initial recharge waters with the various aquifer minerals and gases as groundwater moves downgradient.[28]

Fluoride concentrations in the *lower aquifer* are positively correlated with pH-field levels and negatively correlated with calcium concentrations (Pearson Correlation Coefficient test, $p \leq 0.05$). Fluoride concentrations are found in this aquifer more than quadruple the 4 mg/L health standard. Elevated fluoride concentrations have historically been present in the sub-basin as a 1952 study found two-thirds of sampled wells containing over 1.5 mg/L with samples over 10 mg/L common.[15]

Fluoride concentrations in the *lower aquifer* probably are largely controlled by calcium concentrations through precipitation or dissolution of the mineral fluorite.[22 28] Under equilibrium conditions, smaller concentrations of calcium permit higher fluoride concentrations in solution. Thus, if a source of fluoride ions is available for dissolution, large concentrations of dissolved fluoride may occur if the groundwater is depleted in calcium.[28]

Arsenic concentrations in groundwater may be influenced by groundwater residence time, lithology, and clay mineralogy of the aquifer.[34] The highest concentrations of arsenic are typically associated with the central parts of basins whose chemistries have evolved under closed conditions such as the *lower aquifer* in the San Simon sub-basin.[34]

Groundwater samples in the *lower aquifer* are significantly lighter or depleted which is characteristic of older recharge than those in the *alluvial aquifer, lower aquifer* or *bedrock* based on oxygen-18 and deuterium isotope values (ANOVA with Tukey test, $p \leq 0.05$).

Bedrock - Defined in this report as the Chiricahua, Dos Cabezas, Peloncillo, and Pinaleno Mountains, *bedrock* areas generally have few water quality exceedances and low salinity concentrations though some areas have water quality concerns. Granite areas of the Dos Cabezas and Pinaleno Mountains may exceed gross alpha water health based quality standards. Aesthetics based water quality standards exceedances are more common and include TDS and sulfate in the Chiricahua Mountains, TDS, chloride, fluoride, iron, and manganese in the Dos Cabezas Mountains, TDS and fluoride in the Peloncillo Mountains, and beryllium, uranium, pH, iron, and fluoride in the Pinaleno Mountains. The highest radon concentrations were found at sample sites in the Pinaleno and Dos Cabezas Mountains. Calcium concentrations are positively correlated to hardness, magnesium, bicarbonate, and sulfate concentrations in bedrock. In contrast, sodium concentrations are positively correlated with potassium, bicarbonate, chloride, arsenic, boron, and fluoride concentrations. Nitrate concentrations were positively correlated with both oxygen-18 and deuterium indicating higher nitrate concentrations tend to be the result of more recent recharge (Pearson Correlation Coefficient test, $p \leq 0.05$).

Study Design and Data Evaluation

The 77 groundwater sample sites were generally selected using a modified grid-based, random site-selection approach. This method allowed the spatial distribution of sample sites though the SS although some portions had low sample densities because of the large size of the sub-basin and the paucity of wells and/or springs in certain areas. Based on the available groundwater in the sub-basin, this methodology under represents the groundwater available in basin fill areas compared with the small volume of groundwater available in bedrock areas.[44] Bedrock areas will likely never be used as sites for municipal wells because of limited yields; however, recent patterns of development in the SS have resulted in scattered residences served by private domestic wells, often located in the foothills of the various mountain ranges. Thus, the groundwater quality of bedrock areas is important for much of the new development occurring in the sub-basin.

Most wells sampled were constructed prior to 1980 and lack associated driller logs which specify the location of perforated openings in the well casing. As such, the delineation of which aquifer (or aquifers) a well was pumping water from was sometimes a judgment call made with the assistance of isotopic and temperature data.

Quality assurance procedures were followed and quality control samples were collected to ensure the validity of groundwater quality data. Analysis of equipment blank samples indicated systematic contamination of SC-lab and turbidity; however, the extent of contamination by these parameters was not considered significant. Contamination of blanks by copper, mercury, and chloride on individual field trips was noted but also determined not to be significant.

Analysis of duplicate samples revealed excellent median correlations of less than 2 percent except with turbidity (17 percent). Split samples generally had more variability but still rarely exceeded a maximum difference of 20 percent. In order to interchangeably use groundwater data collected for a previous ADEQ Watershed study with sample data from this groundwater study, two wells sampled in 1997 were resampled in 2002.[37] Results indicated that the maximum difference between sample constituents rarely exceeded 15 percent and statistical tests indicated no significant difference in concentrations.

Data validation was also examined in five QA/QC correlations that affirmed the acceptability of the groundwater quality data for further analysis. Only the groundwater temperature - groundwater depth correlation was not significant (regression analysis, $p \leq 0.05$). The non-significance of this QA/QC correlation is likely due to incomplete groundwater depth information as well as from groundwater depth data influenced by artesian or partial-artesian flows.

Data analysis for this study was conducted using Systat software. The non-normality of most non-transformed data, and the normality of most log-transformed data was determined using the Kolmogorov-Smirnov one-sample test with the Lilliefors option.[8] Spatial variations in constituent concentrations were investigated using the parametric Analysis of Variance (ANOVA) test in conjunction with the Tukey test. Correlations among constituent concentrations were analyzed using the Pearson Correlation Coefficient test.

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Appendix A. Basic Data on Sample Sites, San Simon Sub-Basin

Site #	Cadastral / Pump Type	Latitude - Longitude	ADWR #	ADEQ #	Site Name	Sample Type	Well Depth	Water Depth	Aquifer/ Geology
1st Field Trip, June 12-13, 1997 - Wallin & Hall									
S-A	(D-10-28)36aad Artesian	32°31'24.049" 109°25'32.814"	615746	34438	BLM Hot Well	Inorganic	1920'	--	Lower Aquifer Alluvium
S-B/C	(D-12-29)16bcc Windmill	32°23'25.710" 109°23'51.829"	622814	35773	Antelope Well	Inorganic	836'	104'	Lower Aquifer Alluvium
S-D	(D-13-28)23dbc Turbine pump	32°17'06.819" 109°27'26.984"	618354	36966	Hale #1	Inorganic	750'	407'	Lower Aquifer Alluvium
S-E	(D-13-28)23ddc Turbine pump	32°16'54.000" 109°27'26.000"	--	36967	Hale #2	Inorganic Pesticides	700'	415'	Lower Aquifer Alluvium
S-F	(D-13-29)20ccc Turbine pump	32°16'44.751" 109°24'57.370"	618349	36993	Hale #3	Inorganic, Radiochem Pesticides	700'	327'	Lower Aquifer Alluvium
S-G	(D-13-31)20ada Turbine pump	32°17'23.985" 109°11'36.590"	--	37177	Owens	Inorganic Radiochem	--	73'	Lower Aquifer Alluvium
S-H	(D-13-31)28baa Turbine pump	32°16'44.251" 109°11'06.187"	620750	37192	Marquez	Inorganic Pesticides	600'	120'	Lower Aquifer Alluvium
S-I	(D-14-31)06adc Turbine pump	32°14'33.000" 109°12'55.000"	622763	38192	Parker #1	Inorganic	100'	58'	Upper Aquifer Alluvium
S-J	(D-14-31)10aaa Turbine pump	32°14'11.215" 109°09'31.690"	611805	38207	Chapman #1	Inorganic	750'	166'	Lower Aquifer Alluvium
S-K	(D-14-31)10aba Turbine pump	32°14'10.798" 109°09'46.599"	611804	38208	Chapman #2	Inorganic Radiochem Pesticides	847'	143'	Lower Aquifer Alluvium
S-L	(D-14-31)10daa Turbine pump	32°13'42.542" 109°09'30.998"	611807	38215	Chapman #3	Inorganic	100'	44'	Upper Aquifer Alluvium
S-M	(D-14-31)16dcc Submersible pump	32°14'25.879" 109°11'01.952"	615986	38255	Parker #2	Inorganic	2000'	72'	Lower Aquifer Alluvium
S-N	(D-14-31)29bcc1 Submersible pump	32°11'10.900" 109°12'34.149"	607142	38309	Parker #3	Inorganic	200'	103'	Upper Aquifer Alluvium
S-O	(D-14-31)29bcc2 Turbine pump	32°11'05.000" 109°12'34.134"	607136	56595	Parker #4	Inorganic	1200'	80'	Lower Aquifer Alluvium
S-P	(D-15-31)06aaa Windmill	32°09'41.000" 109°12'39.000"	616049	39175	Parker Windmll	Inorganic Radiochem	154'	--	Upper Aquifer Alluvium
2ne Field Trip, July 31, 2001 - Towne & Boettcher									
SS-1	(D-10-28)36aad Artesian	32°31'24.049" 109°25'32.814"	615746	34438	BLM Hot Well	Inorganic Radon O,H isotopes	1920'	'	Lower Aquifer Alluvium
SS-2	(D-11-29)36cbb Artesian	32°90'045.446" 110°22'08.235"	--	35003	Howard Well	Inorganic	'	'	Lower Aquifer Alluvium
SS-3/4	(D-11-29)01cdd Submersible pump	32°15'41.795" 110°20'50.617"	643384	59954	Rabbit Farm Well	Inorganic	'	'	Lower Aquifer Alluvium
3rd' Field Trip, May 6-8, 2002 -Towne & Harmon (Equipment Blank = SS-14)									
SS-5	(D-9-29)13bdc Submersible pump	32°39'04.783" 109°19'59.181"	615671	34052	Hackberry RanchWell	Inorganic, Radiochem, Radon, O, H isotopes	500'	260'	Lower Aquifer Alluvium
SS-6/7	(D-9-29)34ddd Submersible pump	32°35'57.827" 109°21'28.242"	615672	34053	West Well	Inorganic O, H isotopes	365'	304'	Lower Aquifer Alluvium
SS-8	(D-8-29)22caa Windmill	32°43'20.298" 109°21'55.291"	803573	33415	Rock Well	Inorganic O, H isotopes	--	--	Lower Aquifer Alluvium
SS-9	(D-9-30)33dcd Windmill	32°35'57.968" 109°16'29.297"	615676	34055	Clay Well	Inorganic, Radon O, H isotopes	300'	100'	Bedrock Volcanic
SS-10	(D-10-30)27ddd Submersible pump	32°31'35.891" 109°15'09.968"	615747	59757	Delong RanchWell	Inorganic, Radiochem, Radon, O, H isotopes	--	--	Lower Aquifer Alluvium
SS-11	(D-11-30)15ccb Submersible pump	32°28'19.009" 109°16'37.797"	615822	35006	Joy Valley Well	Inorganic O, H isotopes	160'	139'	Lower Aquifer Alluvium

Appendix A. Basic Data on Sample Sites, San Simon Sub-Basin--Continued

Site #	Cadastral / Pump Type	Latitude - Longitude	ADWR #	ADEQ #	Site Name	Sample Type	Well Depth	Water Depth	Aquifer/ Geology
SS-12	(D-11-30)31ccb Windmill	32°25'45.863" 109°19'38.509"	615823	35007	Ltl. Artesian Well	Inorganic, Radon O, H isotopes	800'	1'	Lower Aquifer Alluvium
SS-13	(D-12-31)026aac Submersible pump	32°25'32.474" 109°12'48.950"	533248	59955	Wolf Well	Inorganic, Radiochem, O, H isotopes	320'	210'	Bedrock Volcanic
SS-15	(D-12-29)25ddc Windmill	32°21'14.018" 109°20'00.144"	643393	59758	West Well	Inorganic, Radon O, H isotopes	61'	50'	Upper Aquifer Alluvium
SS-16	(D-12-30)28bdd Windmill	32°21'47.344" 109°17'17.249"	643397	35778	Yellowham-mer Well	Inorganic O, H isotopes	47'	15'	Upper Aquifer Alluvium
SS-17	(D-13-30)03bdd Windmill	32°19'47.362" 109°16'20.129"	622811	59759	Headquarter Well	Inorganic O, H isotopes	1075'	50'	Lower Aquifer Alluvium
SS-18	(D-12-29)16bcc Windmill	32°23'25.317" 109°23'51.709"	622814	35773	Antelope Well	Inorganic O, H isotopes	836'	150'	Lower Aquifer Alluvium
SS-19/20	(D-11-30)01ccc Submersible pump	32°29'47.610" 109°14'28.680"	622826	59760	North Well	Inorganic, Radiochem, Radon, O, H isotopes	437'	200'	Lower Aquifer Alluvium
SS-21	(D-13-30)15daa Windmill	32°18'02.123" 109°15'42.190"	622806	59761	Garrett Ranch Well	Inorganic O, H isotopes	1100'	25'	Lower Aquifer Alluvium
SS-22	(D-13-31)22cac Windmill	32°17'01.596" 109°10'18.204"	615939	37188	Matt Well	Inorganic, Radon O, H isotopes	200'	100'	Lower Aquifer Alluvium
SS-23	(D-12-31)24dac Submersible pump	32°22'34.016" 109°07'47.783"	622802	35784	McKenzie Ranch Well	Inorganic, Radiochem, O, H isotopes	410'	10'	Bedrock Volcanic
SS-24	(D-13-31)06caa Windmill	32°19'40.352" 109°13'12.993"	622817	59762	Copper Well	Inorganic O, H isotopes	600'	110'	Lower Aquifer Alluvium
4th Field Trip, May 15-16,, 2002 - Towne & Horsley (Equipment Blank SS-34)									
SS-25	(D-11-26)23bcc Windmill	32°27'52.420" 109°40'14.474"	615819	34984	State Land Windmill	Inorganic, Radiochem, Radon, O, H isotopes	500'	'	Bedrock Granite
SS-26	(D-12-27)17dcc Windmill	32°23'003.101" 109°36'35.487"	615872	35689	State Land Windmill	Inorganic O, H isotopes	500'	375'	Lower Aquifer Alluvium
SS-27	(D-14-28)14cbc Windmill	32°12'52.961" 109°27'53.997"	515729	59773	Peterson	Inorganic O, H isotopes	160'	23'	Bedrock Granite
SS-28	(D-15-28)12acc	32°08'43.531" 109°26'23.106"	--	39146	Apache Spring	Inorganic, Radon, O, H isotopes	--	--	Bedrock Granite
SS-29/30	(D-13-28)35bcb Windmill	32°15'45.848" 109°27'54.696"	615927	59774	State Land Windmill	Inorganic, Radiochem, O, H isotopes	640'	378'	Lower Aquifer Alluvium
SS-31a	(D-14-32)11dab Windmill	32°13'42.290" 109°02'56.135"		59775	Section 11 Windmill	Inorganic O, H isotopes	--	--	Upper Aquifer Alluvium
SS-31/32	(D-18-31)08bcb	31°52'57.381" 109°12'24.427"	--	41492	Unnamed Spring	Inorganic, Radiochem, Radon, O, H isotopes	--	--	Bedrock Sedimentary
SS-33	(D-17-30)33abc	31°55'01.609" 109°16'41.420"	--	59776	Barclay Spring	Inorganic O, H isotopes	--	--	Bedrock Volcanic
SS-35	(D-17-30)33dcd	31°54'21.500" 109°16'37.865"	--	40799	Lw Rustler Spring	Inorganic, Radon O, H isotopes	--	--	Bedrock Volcanic
5th Field Trip, May 29-31, 2002 -Towne & Harmon (Equipment Blank = SS-42)									
SS-36	(D-11-26)09bcc Windmill	32°29'33.591" 109°42'15.952"	615817	34981	WA Well	Inorganic, O, H isotopes	70'	49'	Bedrock Granite
SS-37	(D-12-26)10acc Windmill	32°24'20.473" 109°40'43.110"	615864	59790	-	Inorganic, Radiochem, Radon, O, H isotopes	600'	550'	Upper Aquifer Alluvium
SS-38	(D-17-31)27aca Submersible pump	31°55'11.338" 109°09'37.869"	602720	40829	Silver Creek Well	Inorganic, Radiochem, Radon, O, H isotopes	500'	180'	Bedrock Sedimentary
SS-39	(D-18-32)26add Submersible pump	31°50'04.480" 109°03'07.277"	623073	59793	Cloudt Well	Inorganic, Radon O, H isotopes	160'	145'	Alluvial Aquifer Alluvium
SS-40	(D-19-32)28ccc Turbine pump	31°44'28.148" 109°05'09.473"	605460	41977	Many Wells Well	Inorganic O, H isotopes	510'	172'	Alluvial Aquifer Alluvium

Appendix A. Basic Data on Sample Sites, San Simon Sub-Basin--Continued

Site #	Cadastral / Pump Type	Latitude - Longitude	ADWR #	ADEQ #	Well Name	Sample Type	Well Depth	Water Depth	Aquifer/ Geology
SS-41	(D-19-32)33ddc Submersible pump	31°43'35.996" 109°04'13.488"	620644	41984	3 Triangle Well	Inorganic, Radon, O, H isotopes	480'	378'	Alluvial Aquifer Alluvium
SS-43/44	(D-21-31)08dac Submersible pump	31°37'57.952" 109°10'44.287"	642414	59792	Gibbons Ranch	Inorganic Radon, O, H isotopes	700'	600'	Alluvial Aquifer Alluvium
SS-45	(D-20-32)22bbb Windmill	31°40'55.841" 109°04'10.736"	620643	42670	South Windmill	Inorganic O, H isotopes	510'	375'	Alluvial Aquifer Alluvium
SS-46	(C-30-22)13cab Windmill	31°41'45.203" 109°02'00.345"	--	59794	Clover Well	Inorganic, Radiochem, O, H isotopes	--	--	Alluvial Aquifer Alluvium
6th Field Trip, June 11-14, 2002 - Towne & Harmon (Equipment Blank SS-64)									
SS-47	(D-12-26)28bbd Windmill	32°21'55.706" 109°42'10.126"	615867	35682	State Land Windmill	Inorganic Radon, O, H isotopes	500'	280'	Upper Aquifer Alluvium
SS-48	(D-11-25)36abc Windmill	32°26'21.452" 109°44'45.304"	615815	49298	Wood Cyn Windmill	Inorganic, Radiochem, Radon, O, H isotopes	500'	250'	Bedrock Granite
SS-49	(D-13-25)12abb Windmill	32°19'28.935" 109°44'47.257"	615911	36846	State Land Windmill	Inorganic, Radiochem, Radon, O, H isotopes	200'	40'	Bedrock Granite
SS-50	(D-13-26)10cca Windmill	32°18'49.101" 109°40'58.515"	615916	36884	State Land Windmill	Inorganic, Radiochem, O, H isotopes	300'	75'	Bedrock Granite
SS-51	(D-14-31)36dcd Turbine pump	32°09'50.620" 109°07'45.309"	624194	59968	Bohlender	Inorganic, Radon O, H isotopes	800'	220'	Alluvial Aquifer Alluvium
SS-52	(D-15-32)06d Turbine pump	32°08'55.727" 109°06'51.189"	616712	39195	Bohlender	Inorganic O, H isotopes	915'	100'	Alluvial Aquifer Alluvium
SS-53/54	(D-14-31)25bcd Turbine pump	32°11'06.813" 109°08'10.347"	626398	59831	Bohlender	Inorganic O, H isotopes	810'	215'	Alluvial Aquifer Alluvium
SS-55	(D-15-30)17ad Windmill	32°07'38.225" 109°17'43.211"	802388	59832	Cross J Windmill	Inorganic, Radiochem, Radon, O, H isotopes	100'	40'	Bedrock Sedimentary
SS-56	(D-15-30)15ddd Submersible pump	32°07'16.186" 109°15'45.525"	--	59833	Dunn Spring	Inorganic, Radon O, H isotopes	--	--	Bedrock Sedimentary
SS-57	(D-15-29)15acd Submersible pump	32°07'54.617" 109°22'08.842"	642724	39163	Maulkins RanchWell	Inorganic, Radiochem Radon O, H isotopes	40'	'	Bedrock Granite
SS-58/59	(D-21-31)23ccc Submersible pump	31°34'59.003" 109°09'53.309"	642412	59834	Gibbons	Inorganic, Radon O, H isotopes	900'	600'	Bedrock Basaltic
SS-60	(C-26-21)24baa Turbine pump	32°02'11.113" 109°02'32.076"	--	59981	Lake Well	Inorganic O, H isotopes	200'	40'	Alluvial Aquifer Alluvium
SS-61	(D-15-32)34dcd Submersible pump	32°03'09.481" 109°02'49.720"	--	59982	State Line Well	Inorganic O, H isotopes			Alluvial Aquifer Alluvium
SS-62	(D-20-30)36caa Submersible pump	31°38'47.412" 109°14'13.307"	648082	42652	Gibbons	Inorganic, Radon, O, H isotopes	800'	710'	Alluvial Aquifer Alluvium
SS-63	(D-19-32)18cbd Submersible pump	31°46'29.497" 109°06'55.748"	577580	59835	Dennison	Inorganic, Radiochem, O, H isotopes	465'	336'	Alluvial Aquifer Alluvium
SS-65	(D-17-31)26acc Windmill	31°55'05.737" 109°08'38.620"	612941	40819	Portal Land Co. Well	Inorganic, Radon, O, H isotopes	275'	80'	Bedrock Sedimentary
SS-66	(D-18-31)08	--	--	--	Cave Creek	O, H isotopes	-	-	Surface Water
SS-67	(D-15-30)35bbb Windmill	32°05'19.715" 109°15'32.620"	–	39170	Windmill	Inorganic, Radon, O, H isotopes	–	--	Bedrock Volcanic
7th Field Trip, September 10-13, 2002 - Towne & Mihalic (Equipment Blanks SS-76 & 77)									
SS-68	(D-11-28)31ccd Windmill	32°25'44.654" 109°31'51.992"	615821	34990	Corral Well	Inorganic Radon, O, H isotopes	169'	62'	Upper Aquifer Alluvium
SS-69/70	(D-12-28)27ccb Turbine pump	32°21'22.753" 109°28'59.531"	625837	35738	Irrigation Well	Inorganic, O, H isotopes	800'	'	Lower Aquifer Alluvium
SS-71/72	(D-13-31)20dad Submersible pump	32°17'01.406" 109°11'50.875"	621287	37182	Trailer Well	Inorganic, Radon, O, H isotopes	300'	'	Upper Aquifer Alluvium

Appendix A. Basic Data on Sample Sites, San Simon Sub-Basin--Continued

Site #	Cadastral / Pump Type	Latitude - Longitude	ADWR #	ADEQ #	Well Name	Sample Type	Well Depth	Water Depth	Aquifer/ Geology
SS-73/74	(D-13-31)21ccd Submersible pump	32°16'44.146" 109°11'06.031"	--	62317	Marques HouseWell	Inorganic, Radon, O, H isotopes	125'	-	Upper Aquifer Alluvium
SS-75	(D-13-32)09abd Windmill	32°19'22.270" 109°07'47.783"	615940	37271	CowSpring Well	Inorganic, Radon O, H isotopes	40'	-	Bedrock Volcanic
SS-78	(D-16-31)29bdd Submersible pump	32°00'28.264" 109°11'43.154"	647868	39977	Tank Well	Inorganic, Radiochem, O, H isotopes	195'	80'	Bedrock Sedimentary
SS-79/80	(D-19-30)15ddd	31°46'19.161" 109°15'36.096"	--	60555	Price Spring	Inorganic, Radiochem, Radon, O, H isotopes	-	-	Bedrock Volcanic
SS-81	(D-14-31)04ada Turbine pump	32°14'50.574" 109°10'43.371"	541143	60240	Irrigation Well	Inorganic & O, H isotopes	750'	120'	Lower Aquifer Alluvium
SS-82	(D-14-31)10bbb Turbine pump	32°14'01.929" 109°10'18.794"	621226	38210	Noland Well	Inorganic & O, H isotopes	100	50'	Upper Aquifer Alluvium

Appendix B. Groundwater Quality Data, San Simon Sub-Basin

Site #	MCL Exceedances	Temp (^{o}C)	pH-field (su)	pH-lab (su)	SC-field (µS/cm)	SC-lab (µS/cm)	T. Alk (mg/L)	TDS (mg/L)	Hardness (mg/L)	Hard (cal) (mg/L)	Turbidity (NTU)
S-A	TDS, SO_4, **F**, As*	42.1	8.17	8.5	1673	1465	160	**990**	22	-	--
S-B/C	TDS, Cl, SO_4,, **F**, As*	27.4	8.21	8.05	2110	2100	140	**1400**	67.5	-	1.07
S-D	TDS, SO_4	28.4	7.38	7.9	1229	1200	110	**850**	390	-	0.27
S-E	TDS, SO_4	26.6	7.21	8.0	1312	1300	120	**890**	400	-	4.0
S-F	-	27.3	7.78	8.0	396	400	140	270	85	-	0.09
S-G	F	31.2	7.83	8.2	375	380	110	260	85	-	0.01
S-H	TDS, SO_4, **F**	21.5	7.54	8.1	1338	1300	200	**940**	300	-	0.33
S-I	TDS, SO_4, **F**	20.9	7.17	7.9	2440	2400	250	**1800**	550	-	0.96
S-J	-	27.3	7.64	7.9	410	410	120	290	130	-	0.09
S-K	Fe	27.9	7.65	7.7	445	450	110	320	160	-	0.07
S-L	TDS, Cl, SO_4, NO_3-N, F, Be	20.4	6.90	7.2	5520	5500	300	**4600**	1300	-	0.09
S-M	pH, **F**, As*	24.9	**8.86**	8.8	258	260	74	180	20	-	0.13
S-N	-	21.9	7.44	8.1	627	620	160	420	200	-	0.03
S-O	F	32.6	7.94	8.1	491	500	140	340	64	-	0.08
S-P	-	22.9	7.65	8.0	581	570	160	390	200	-	6.3
SS-1	TDS,SO_4, **F**, As	40.5	8.47	*8.6*	1540	1700	160	**1000**	18	16	*0.02*
SS-2	pH, TDS, **F**, As	31.6	**8.85**	*8.9*	1008	1000	200	**620**	22	20	*0.06*
SS-3/4	pH, TDS, **F**, As*	29.4	**8.99**	*9.0*	1151	1200	210	**800**	ND	ND	*0.03*
SS-5	TDS, F	23.4	8.01	*8.0*	818	860	170	**530**	130	130	*0.05*
SS-6/7	pH, TDS, F, As*	28.8	**8.64**	*8.55*	1092	1100	245	**700**	13.5	14	*0.07*
SS-8	TDS	26.8	8.01	*7.8*	1419	1400	86	**860**	140	140	*21*
SS-9	TDS, SO_4, As*	24.1	7.99	*8.0*	1343	1400	170	**880**	100	100	*1.2*
SS-10	TDS, Cl, SO_4, As*,	35.1	8.26	*8.4*	2312	2400	110	**1500**	56	59	*0.05*
SS-11	TDS, F	26.4	8.38	*8.3*	1313	1400	250	**850**	35	35	*0.23*
SS-12	TDS, SO_4, **F**, As*	26.4	8.29	*8.3*	995	1000	110	**680**	71	78	*0.23*
SS-13	-	24.8	8.09	*8.0*	436	450	190	290	100	100	*0.41*
SS-15	TDS, SO_4, F	22.2	7.96	*8.1*	1469	1500	220	**1100**	130	120	*0.18*
SS-16	TDS, **F**, As*	22.5	7.52	*7.6*	1023	1100	400	**690**	100	100	*0.33*
SS-17	TDS, **F**, As*	23.3	7.85	*7.9*	808	870	240	**560**	110	100	*0.49*

bold = parameter level exceeds Primary or Secondary MCL
* = concentration exceeds the revised arsenic SDW Primary MCL which becomes effective in 2006
ND = not detected above minimum reporting level
F = Fluoride Primary MCL exceedance

Appendix B. Groundwater Quality Data, San Simon Sub-Basin--Continued

Site #	MCL Exceedances	Temp (°C)	pH-field (su)	pH-lab (su)	SC-field (µS/cm)	SC-lab (µS/cm)	T. Alk (mg/L)	TDS (mg/L)	Hardness (mg/L)	Hard (cal) (mg/l)	Turbidity (NTU)
SS-18	TDS, Cl, SO_4, **F**,As*,	27.7	8.29	*8.2*	2170	2300	140	**1300**	51	52	*4.0*
SS-19/20	TDS, Cl, SO_4, **F**,As*,	42.3	7.19	*7.4*	3129	3200	275	**2100**	230	225	*0.29*
SS-21	pH, TDS, **F**, As*	25.2	**9.02**	*8.9*	1563	1700	710	**1000**	ND	ND	*1.0*
SS-22	**F**	24.5	8.32	*7.8*	308	330	100	240	30	38	*2.7*
SS-23	-	25.7	7.14	*7.0*	375	390	150	270	71	77	*0.18*
SS-24	**F**, As*	22.8	8.09	*7.9*	596	640	170	430	73	79	*0.51*
SS-25	F, Be	24.8	7.05	6.8	347	350	130	210	110	110	0.56
SS-26	-	28.6	7.87	7.7	492	490	150	290	61	64	*4.5*
SS-27	TDS, F, Fe, Mn	24.2	7.09	7.6	883	880	260	**540**	310	310	*46*
SS-28	-	--	7.22	7.4	617	590	240	340	280	280	*0.02*
SS-29/30	-	25.6	7.82	7.85	529	525	150	320	120	120	*3.5*
SS-31a	TDS	20.4	8.08	7.9	942	940	170	**570**	170	170	*0.40*
SS-31/32	TDS, SO_4	24.8	7.30	7.1	1384	1350	130	**1100**	735	750	*0.06*
SS-33	-	11.7	8.21	6.7	95	85	25.1	56	26	30	*0.09*
SS-35	-	10.0	7.02	6.6	82	79	28	60	26	28	*1.0*
SS-36	TDS	39.0	7.34	7.4	932	930	330	**590**	340	350	*0.04*
SS-37	-	25.8	7.70	7.2	307	320	120	190	83	83	*26*
SS-38	TDS, SO_4	22.5	7.11	7.1	1317	1400	240	**1100**	760	770	*0.15*
SS-39	**F**	22.3	8.27	7.8	257	265	88	200	50	52	*0.03*
SS-40	-	22.2	7.85	7.3	181	180	74	130	58	61	*0.37*
SS-41	-	22.4	7.58	7.2	166	180	69	130	58	60	*0.16*
SS-43/44	-	28.4	7.68	7.8	352	350	170	235	110	110	*0.17*
SS-45	-	24.6	7.73	7.4	268	290	120	180	92	91	*5.9*
SS-46	-	22.1	7.78	7.4	224	240	100	170	69	70	*0.79*
SS-47	-	24.6	7.84	7.7	414	440	150	270	64	65	*2.0*
SS-48	pH, gross α, Fe uranium	27.2	**8.79**	8.8	463	480	200	290	ND	ND	*5.5*
SS-49	TDS, Cl, F, gross α	28.9	7.76	7.9	1851	1900	330	**1100**	410	390	*1.1*
SS-50	TDS, F, gross α	23.5	7.26	7.4	1185	1200	370	**750**	280	260	*0.84*

bold = parameter level exceeds Primary or Secondary MCL
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ND = not detected above minimum reporting level
F = Fluoride Primary MCL exceedance

Appendix B. Groundwater Quality Data, San Simon Sub-Basin--Continued

Site #	MCL Exceedances	Temp (°C)	pH-field (su)	pH-lab (su)	SC-field (µS/cm)	SC-lab (µS/cm)	T. Alk (mg/L)	TDS (mg/L)	Hardness (mg/L)	Hard (cal) (mg/L)	Turbidity (NTU)
SS-51	-	27.8	7.79	7.6	386	380	120	260	130	130	*0.20*
SS-52	F	27.3	7.98	7.5	374	390	110	250	100	100	*0.02*
SS-53/54	TDS, $S0_4$	26.3	7.60	7.5	1364	1400	140	**1000**	510	500	*0.014*
SS-55	Fe, Mn	21.5	7.56	7.4	682	700	210	460	350	320	*100*
SS-56	-	20.7	7.54	7.4	631	670	240	420	320	320	*0.20*
SS-57	TDS	20.3	7.13	7.4	803	870	260	**570**	400	400	*0.04*
SS-58/59	-	28.8	8.13	7.85	332	340	150	215	70.5	72.5	*1.15*
SS-60	F	22.7	8.00	7.8	410	430	150	270	100	110	*0.02*
SS-61	-	22.2	8.11	7.6	563	600	160	390	160	170	*0.35*
SS-62	F	29.7	7.83	7.5	381	400	180	250	160	160	*ND*
SS-63	-	24.9	7.17	6.6	118	120	33	120	18	19	*2.0*
SS-65	-	20.3	7.46	7.4	528	550	180	350	240	240	*0.82*
SS-67	Fe, Mn	22.5	7.28	6.8	295	310	120	190	120	120	*5.5*
SS-68	NO_3	--	7.34	7.5	555	560	160	370	180	180	1.4
SS-69/70	-	30.2	8.12	7.3	460	480	66	300	66	69	0.04
SS-71/72	pH, F	25.1	**9.03**	8.9	437	480	150	280	ND	ND	0.48
SS-73/74	TDS, $S0_4$, F	25.1	7.36	6.9	1744	1900	230	**1300**	350	360	0.16
SS-75	TDS, F	--	7.61	6.9	832	870	300	**560**	270	270	0.19
SS-78	-	22.8	7.35	7.4	692	760	240	480	350	370	0.02
SS-79/80	-	19.1	8.34	6.23	59	64	12	68	14	11	3.2
SS-81	-	26.9	7.23	7.1	663	710	110	480	210	230	0.12
SS-82	TDS, $S0_4$, NO_3, F	21.1	6.95	7.2	4728	5100	360	**4100**	1100	1200	0.18

bold = parameter level exceeds Primary or Secondary MCL
* = concentration exceeds the revised arsenic SDW Primary MCL which becomes effective in 2006
ND = not detected above minimum reporting level
F = Fluoride Primary MCL exceedance

Appendix B. Groundwater Quality Data, San Simon Sub-Basin--Continued

Site #	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Chloride (mg/L)	Sulfate (mg/L)
S-A	7.9	0.63	340	3.9	220	ND	150	**290**
S-B/C	24	1.55	435	6.15	170	ND	**320**	**435**
S-D	120	25	120	3.5	130	ND	150	**310**
S-E	120	30	130	2.0	150	ND	150	**320**
S-F	31	3.0	56	5.7	170	ND	14	40
S-G	34	1.9	51	2.2	130	ND	15	59
S-H	97	18	190	4.6	240	ND	50	**410**
S-I	160	36	360	5.8	310	ND	210	**750**
S-J	50	3.8	42	2.6	150	ND	8.9	84
S-K	62	4.4	40	2.6	130	ND	15	97
S-L	470	68	990	14	370	ND	**380**	**2700**
S-M	8.4	ND	54	1.2	77	6.5	21	30
S-N	71	11	57	1.7	200	ND	43	120
S-O	26	1.7	90	2.0	170	ND	13	90
S-P	66	12	50	1.4	200	ND	32	89
SS-1	6.4	ND	340	3.0	180	6.7	200	**310**
SS-2	6.2	1.2	210	2.1	210	16	58	200
SS-3/4	2.2	ND	250	2.1	210	22	47	240
SS-5	31	14	120	11	210	ND	74	120
SS-6/7	3.05	1.65	235	6.7	235	11	105	145
SS-8	38	10	220	8	100	ND	180	230
SS-9	27	8.8	250	10	210	ND	140	**270**
SS-10	18	3.4	460	16	120	4.7	**370**	**430**
SS-11	9.3	3.0	280	9.4	300	ND	110	200
SS-12	25	4.0	180	5.8	130	ND	33	**290**
SS-13	28	8.7	58	3.2	230	ND	16	14
SS-15	28	13	290	4.8	270	ND	49	**470**
SS-16	26	9.4	210	1.8	490	ND	14	120
SS-17	28	8.6	150	1.9	290	ND	23	140

bold = parameter level exceeds Primary or Secondary MCL   ND = not detected above minimum reporting level

Appendix B. Groundwater Quality Data, San Simon Sub-Basin--Continued

Site #	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Chloride (mg/L)	Sulfate (mg/L)
SS-18	19	1.1	440	5.5	170	ND	**320**	**430**
SS-19/20	78.5	7.45	600	17.5	335	ND	**415**	**620**
SS-21	1.0	ND	420	2.5	760	50	12	120
SS-22	13	1.4	56	3.6	120	ND	4.3	33
SS-23	23	4.9	57	2.0	180	ND	9.8	32
SS-24	22	5.8	110	4.6	210	ND	23	91
SS-25	31	7.4	28	1.2	160	ND	12	ND
SS-26	21	2.7	78	5.1	180	ND	22	37
SS-27	81	27	69	1.8	320	ND	33	150
SS-28	100	7.5	12	1.1	290	ND	10	46
SS-29/30	40	5.2	62.5	2.8	180	ND	36.5	49.5
SS-31a	47	14	120	2.8	210	ND	89	120
SS-31/32	265	22	21	2.2	160	ND	4.6	**645**
SS-33	8.4	2.1	4.1	0.87	31	ND	1.8	ND
SS-35	8.4	1.6	4.3	0.89	34	ND	1.3	ND
SS-36	91	31	76	ND	400	ND	28	140
SS-37	28	3.2	32	2.8	150	ND	13	8.1
SS-38	250	35	28	1.2	290	ND	7.7	**590**
SS-39	19	1.2	35	2.3	110	ND	16	9.1
SS-40	19	3.5	13	2.8	90	ND	6.0	4.1
SS-41	19	3.1	11	2.5	84	ND	6.3	3.8
SS-43/44	33	6.9	32.5	7.75	210	ND	5.25	7.5
SS-45	30	4.0	22	3.6	150	ND	8.1	5.4
SS-46	26	1.2	22	0.56	120	ND	6.0	4.0
SS-47	17	5.6	68	0.90	180	ND	24	17
SS-48	2.2	ND	110	0.56	220	12	19	6.6
SS-49	100	35	250	0.73	400	ND	**280**	240
SS-50	74	19	170	0.56	450	ND	74	180
SS-51	41	5.8	30	2.0	146	ND	6.2	66

bold = parameter level exceeds Primary or Secondary MCL   ND = not detected above minimum reporting level

Appendix B. Groundwater Quality Data, San Simon Sub-Basin--Continued

Site #	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Chloride (mg/L)	Sulfate (mg/L)
SS-52	35	4.5	38	1.8	130	ND	5.8	63
SS-53/54	150	33	100	2.85	170	ND	94	**455**
SS-55	100	18	17	0.85	260	ND	7.1	160
SS-56	96	20	10	0.84	290	ND	8.3	98
SS-57	120	24	28	1.1	320	ND	17	170
SS-58/59	16	7.45	37.5	8.4	181.5	ND	5.4	5.6
SS-60	39	2.2	50	2.1	180	ND	7.5	49
SS-61	62	2.9	60	2.8	200	ND	9.0	120
SS-62	55	6.7	16	3.7	220	ND	6.3	8.2
SS-63	5.7	1.1	17	1.6	40	ND	4.0	16
SS-65	80	11	18	0.99	220	ND	4.0	100
SS-66	-	-	-	-	-	-	-	-
SS-67	36	6.6	16	0.66	150	ND	4.5	27
SS-68	58	8	38	2.4	200	ND	15	28
SS-69/70	24	2	64	1.95	80	ND	58	67
SS-71/72	2.4	ND	98	1.3	160	13	5.1	47
SS-73/74	110	20	265	4.9	280	ND	80	**580**
SS-75	84	14	87	ND	370	ND	29	130
SS-78	120	17	18	1.1	290	ND	7.6	160
SS-79/80	4.6	1.0	5.8	1.25	16	ND	1.8	10.5
SS-81	84	5.5	54	3.0	130	ND	41	170
SS-82	390	55	820	10	440	ND	190	**2100**

bold = parameter level exceeds Primary or Secondary MCL   ND = not detected above minimum reporting level

Appendix B. Groundwater Quality Data, San Simon Sub-Basin--Continued

Site #	Nitrate-Nitrite-N (mg/L)	Nitrate - N (mg/L)	Nitrite-N (mg/L)	TKN (mg/L)	Ammonia-N (mg/L)	Phosphorus (mg/L)	SAR (value)	Irrigation Quality
S-A	ND	ND	-	0.25	ND	ND	31.5	C3 - S4
S-B/C	ND	ND	-	ND	ND	ND	23.1	C3 - S4
S-D	0.51	0.51	-	0.14	ND	ND	2.6	C3 - S1
S-E	0.71	0.71	-	0.20	ND	ND	2.8	C3 - S1
S-F	0.96	0.96	-	ND	ND	ND	2.4	C2 - S1
S-G	0.46	0.46	-	0.20	ND	ND	2.3	C2 - S1
S-H	6.8	6.8	-	0.37	ND	ND	4.7	C2 - S1
S-I	8.9	8.9	-	0.46	ND	ND	6.7	C4 - S2
S-J	0.62	0.62	-	0.15	ND	ND	1.5	C2 - S1
S-K	1.2	1.2	-	0.20	ND	ND	1.3	C2 - S1
S-L	**31**	**31**	-	0.78	ND	ND	11.3	C4 - S4
S-M	ND	ND	-	0.22	ND	ND	5.1	C2 - S1
S-N	0.64	0.64	-	0.31	ND	ND	1.7	C2 - S1
S-O	0.31	0.31	-	ND	ND	ND	4.6	C2 - S1
S-P	0.42	0.42	-	0.15	ND	ND	1.5	C2 - S1
SS-1	ND	ND	*ND*	0.14	ND	0.022	37	C3 - S4
SS-2	0.42	ND	*ND*	ND	ND	ND	20.2	C3 - S4
SS-3/4	ND	ND	*ND*	ND	ND	ND	46.4	C3 - S4
SS-5	2.3	2.3	*ND*	ND	ND	ND	4.5	C3 - S1
SS-6/7	2.3	2.3	*ND*	ND	ND	ND	27.8	C3 - S4
SS-8	0.27	0.11	*0.16*	ND	ND	ND	8.2	C3 -S2
SS-9	1.2	1.2	*ND*	ND	ND	ND	10.7	C3 - S3
SS-10	0.84	0.78	*0.056*	ND	ND	ND	26.1	C4 - S4
SS-11	0.065	0.065	*ND*	0.065	0.040	0.024	20.4	C3 - S3
SS-12	0.36	0.36	*ND*	ND	ND	ND	8.8	C3 - S2
SS-13	0.82	0.82	*ND*	0.073	ND	ND	2.5	C2 - S1
SS-15	0.15	0.15	*ND*	ND	ND	ND	11.4	C3 - S2
SS-16	0.080	0.080	*ND*	ND	ND	0.055	9	C3 - S2
SS-17	0.41	0.41	*ND*	ND	ND	ND	6.4	C3 - S2

bold = parameter level exceeds Primary or Secondary MCL   ND = not detected above minimum reporting level
Irrigation Quality - C = salinity hazard, S = sodium hazard, 1 = low, 2 = medium, 3 = high, 4 = very high

Appendix B. Groundwater Quality Data, San Simon Sub-Basin—Continued

Site #	**Nitrate-Nitrite-N** (mg/L)	**Nitrate - N** (mg/L)	**Nitrite-N** (mg/L)	**TKN** (mg/L)	**Ammonia-N** (mg/L)	**Phosphorus** (mg/L)	**SAR** (value)	**Irrigation Quality**
SS-18	0.054	0.054	*ND*	ND	ND	ND	26.6	C4 - S4
SS-19/20	0.54	0.54	*ND*	ND	ND	ND	17.2	C4 - S4
SS-21	ND	ND	*ND*	0.82	0.34	0.10	115.7	C3 - S4
SS-22	ND	ND	*ND*	ND	ND	ND	3.9	C2 - S1
SS-23	0.90	0.90	*ND*	ND	ND	0.046	2.8	C2 - S1
SS-24	0.59	0.59	*ND*	ND	ND	ND	5.4	C2 - S1
SS-25	1.7	1.7	*ND*	ND	ND	ND	1.2	C2 - S1
SS-26	5.2	5.2	*ND*	ND	ND	ND	4.3	C2 - S1
SS-27	0.054	0.054	*ND*	ND	ND	ND	1.7	C2 - S1
SS-28	2.3	2.3	*ND*	ND	ND	ND	0.3	C2 - S1
SS-29/30	0.255	0.255	*ND*	ND	ND	ND	2.5	C2 - S1
SS-31a	8.6	8.6	*ND*	0.11	ND	0.020	4	C3 - S1
SS-31/32	0.02	0.02	ND	0.065	ND	0.026	0.3	C3 - S1
SS-33	0.57	0.57	ND	0.078	0.028	0.063	0.3	C1 - S1
SS-35	0.13	0.13	ND	ND	ND	0.045	0.4	C1 - S1
SS-36	0.19	0.19	*ND*	ND	ND	ND	1.8	C3 - S1
SS-37	2.56	2.48	*0.082*	0.094	0.054	0.022	1.5	C2 - S1
SS-38	0.26	0.26	ND	0.056	ND	ND	0.4	C3 - S1
SS-39	0.96	0.96	ND	ND	ND	ND	2.1	C2 - S1
SS-40	1.0	1.0	ND	ND	ND	0.087	0.7	C1 - S1
SS-41	0.87	0.87	ND	0.050	ND	0.038	0.6	C1 - S1
SS-43/44	0.49	0.49	ND	1.4	ND	ND	1.3	C2 - S1
SS-45	0.60	0.60	ND	ND	ND	ND	1	C2 - S1
SS-46	0.65	0.65	ND	ND	ND	0.022	1.2	C1 - S1
SS-47	3.5	3.5	*ND*	ND	ND	ND	3.7	C2 - S1
SS-48	1.3	1.3	*ND*	0.05	ND	ND	20.4	C2 - S3
SS-49	4.0	4.0	*ND*	0.098	ND	ND	5.5	C3 - S1
SS-50	0.55	0.55	*ND*	ND	ND	0.022	4.6	C3 - S1

bold = parameter level exceeds Primary or Secondary MCL   ND = not detected above minimum reporting level
Irrigation Quality - C = salinity hazard, S = sodium hazard, 1 = low, 2 = medium, 3 = high, 4 = very high

Appendix B. Groundwater Quality Data, San Simon Sub-Basin--Continued

Site #	Nitrate-Nitrite-N (mg/L)	Nitrate - N (mg/L)	Nitrite-N (mg/L)	TKN (mg/L)	Ammonia-N (mg/L)	Phosphorus (mg/L)	SAR (value)	Irrigation Quality
SS-51	0.44	0.44	*ND*	ND	ND	ND	1.2	C2 - S1
SS-52	0.43	0.43	*ND*	ND	ND	ND	1.6	C2 - S1
SS-53/54	4.6	4.6	*ND*	0.84	ND	ND	1.9	C3 - S1
SS-55	0.31	0.31	*ND*	0.58	0.023	0.10	0.4	C2 - S1
SS-56	0.95	0.95	*ND*	0.40	0.028	0.021	0.3	C2 - S1
SS-57	0.41	0.41	*ND*	0.078	ND	ND	0.6	C3 - S1
SS-58/59	0.88	0.88	*ND*	ND	ND	ND	0.9	C2 - S1
SS-60	0.70	0.70	ND	ND	ND	ND	2.1	C2 - S1
SS-61	0.49	0.49	ND	ND	ND	ND	2	C2 - S1
SS-62	0.57	0.57	ND	ND	ND	ND	0.5	C2 - S1
SS-63	0.43	0.43	ND	ND	ND	0.16	1.7	C1 - S1
SS-65	0.32	0.32	ND	ND	ND	0.027	0.5	C2 - S2
SS-66	-	-	-	-	-	-	-	-
SS-67	0.070	0.070	ND	ND	0.023	0.086	0.7	C2 - S1
SS-68	**18**	**18**	ND	ND	ND	ND	1.2	C2 - S1
SS-69/70	2.0	2.0	ND	ND	ND	ND	3.4	C2 - S1
SS-71/72	ND	ND	ND	0.15	0.12	0.027	17.4	C2 - S3
SS-73/74	8.6	8.6	ND	0.064	ND	ND	6.2	C3 - S2
SS-75	0.52	0.52	ND	0.070	ND	0.028	2.3	C3 - S1
SS-78	1.0	1.0	ND	ND	ND	0.024	0.4	C3 - S1
SS-79/80	ND	ND	ND	0.082	ND	ND	0.7	C1 - S1
SS-81	2.4	2.4	ND	ND	ND	ND	1.5	C2 - S1
SS-82	**30**	**30**	ND	0.38	ND	0.038	10.3	C4 - S3

bold = parameter level exceeds Primary or Secondary MCL   ND = not detected above minimum reporting level
Irrigation Quality - C = salinity hazard, S = sodium hazard, 1 = low, 2 = medium, 3 = high, 4 = very high

Appendix B. Groundwater Quality Data, San Simon Sub-Basin—Continued

Site #	Antimony (mg/L)	Arsenic (mg/L)	Barium (mg/L)	Beryllium (mg/L)	Boron (mg/L)	Cadmium (mg/L)	Chromium (mg/L)	Copper (mg/L)	Fluoride (mg/L)
S-A	ND	0.032*	ND	ND	0.37	ND	ND	ND	**10**
S-B/C	ND	0.043*	ND	ND	0.52	ND	ND	ND	**7.45**
S-D	ND	ND	ND	ND	0.10	ND	ND	ND	0.23
S-E	ND	ND	ND	ND	0.10	ND	ND	ND	0.51
S-F	ND	ND	ND	ND	ND	ND	ND	ND	1.5
S-G	ND	ND	ND	ND	ND	ND	ND	ND	**2.1**
S-H	ND	ND	ND	ND	0.22	ND	ND	ND	**5.3**
S-I	ND	ND	ND	ND	0.17	ND	ND	ND	**4.1**
S-J	ND	ND	ND	ND	ND	ND	ND	0.011	0.83
S-K	ND	ND	ND	ND	ND	ND	ND	0.064	0.93
S-L	ND	ND	ND	**.00061**	0.68	ND	ND	ND	**3.8**
S-M	ND	0.022*	ND	ND	ND	ND	ND	ND	**11**
S-N	ND	ND	ND	ND	ND	ND	ND	ND	0.41
S-O	ND	ND	ND	ND	ND	ND	ND	ND	**2.8**
S-P	ND	ND	ND	ND	ND	ND	ND	0.014	0.73
SS-1	ND	**0.053**	ND	ND	0.36	ND	ND	ND	**11**
SS-2	ND	**0.060**	ND	ND	0.28	ND	ND	ND	**6**
SS-3/4	ND	0.030*	ND	ND	0.49	ND	ND	ND	**17**
SS-5	ND	ND	ND	ND	0.27	ND	ND	ND	**2.0**
SS-6/7	ND	0.012*	ND	ND	0.32	ND	ND	ND	**2.1**
SS-8	ND	ND	ND	ND	0.19	ND	ND	ND	0.89
SS-9	ND	0.022*	ND	ND	0.40	ND	ND	ND	**3.7**
SS-10	ND	0.011*	ND	ND	0.24	ND	ND	ND	0.86
SS-11	ND	ND	ND	ND	0.50	ND	ND	ND	**2.1**
SS-12	ND	0.026*	ND	ND	0.34	ND	ND	ND	**4.5**
SS-13	ND	ND	ND	ND	ND	ND	ND	ND	1.3
SS-15	ND	ND	ND	ND	1.3	ND	ND	ND	**2.6**
SS-16	ND	0.029*	ND	ND	0.18	ND	ND	ND	**7.9**

bold = parameter level exceeds Primary or Secondary MCL ND = not detected above minimum reporting level
* = concentration exceeds the revised arsenic SDWA Primary MCL of 0.01 mg/L which becomes effective in 2006

Appendix B. Groundwater Quality Data, San Simon Sub-Basin—Continued

Site #	Antimony (mg/L)	Arsenic (mg/L)	Barium (mg/L)	Beryllium (mg/L)	Boron (mg/L)	Cadmium (mg/L)	Chromium (mg/L)	Copper (mg/L)	Fluoride (mg/L)
SS-17	ND	0.013*	ND	ND	0.19	ND	ND	ND	**5.7**
SS-18	ND	00.34*	ND	ND	0.49	ND	ND	ND	**7.1**
SS-19/20	ND	0.012*	ND	ND	0.68	ND	ND	ND	**4.9**
SS-21	ND	0.016*	ND	ND	4.0	ND	ND	ND	**15**
SS-22	ND	ND	ND	ND	0.14	ND	ND	ND	**7.6**
SS-23	ND	ND	ND	ND	ND	ND	ND	ND	0.71
SS-24	ND	0.013*	ND	ND	0.36	ND	ND	ND	**5.6**
SS-25	ND	ND	ND	**.0019**	ND	ND	ND	0.016	**3.6**
SS-26	ND	ND	ND	ND	0.20	ND	ND	ND	1.1
SS-27	ND	ND	ND	ND	ND	ND	ND	ND	**2.9**
SS-28	ND	ND	ND	ND	ND	ND	ND	ND	0.47
SS-29/30	ND	ND	ND	ND	ND	ND	ND	ND	0.23
SS-31a	ND	ND	ND	ND	0.28	ND	ND	ND	0.95
SS-31/32	ND	ND	ND	ND	ND	ND	ND	ND	0.91
SS-33	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-35	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-36	ND	ND	ND	ND	ND	ND	ND	0.040	0.74
SS-37	ND	ND	ND	ND	ND	ND	ND	ND	0.71
SS-38	ND	ND	ND	ND	ND	ND	ND	ND	0.44
SS-39	ND	ND	ND	ND	ND	ND	ND	ND	**4.1**
SS-40	ND	ND	ND	ND	ND	ND	ND	ND	0.40
SS-41	ND	ND	ND	ND	ND	ND	ND	ND	0.32
SS-43/44	ND	ND	ND	ND	ND	ND	ND	ND	1.5
SS-45	ND	ND	ND	ND	ND	ND	ND	ND	0.99
SS-46	ND	ND	ND	ND	ND	ND	ND	ND	0.24
SS-47	ND	0.017*	ND	ND	0.13	ND	ND	ND	1.1
SS-48	ND	0.017*	ND	ND	0.12	ND	ND	0.012	1.3
SS-49	ND	ND	ND	ND	0.30	ND	ND	0.058	**3.6**

bold = parameter level exceeds Primary or Secondary MCL ND = not detected above minimum reporting level
* = concentration exceeds the revised arsenic SDWA Primary MCL of 0.01 mg/L which becomes effective in 2006

Appendix B. Groundwater Quality Data, San Simon Sub-Basin--Continued

Site #	Antimony (mg/L)	Arsenic (mg/L)	Barium (mg/L)	Beryllium (mg/L)	Boron (mg/L)	Cadmium (mg/L)	Chromium (mg/L)	Copper (mg/L)	Fluoride (mg/L)
SS-50	ND	ND	ND	ND	0.12	ND	ND	0.028	**2.6**
SS-51	ND	ND	ND	ND	ND	ND	ND	ND	1.1
SS-52	ND	ND	ND	ND	ND	ND	ND	ND	**2.3**
SS-53/54	ND	ND	0.022	ND	ND	ND	ND	ND	0.59
SS-55	ND	ND	ND	ND	ND	ND	ND	ND	0.28
SS-56	ND	ND	ND	ND	ND	ND	ND	ND	0.30
SS-57	ND	ND	ND	ND	ND	ND	ND	ND	0.72
SS-58/59	ND	ND	ND	ND	ND	ND	ND	ND	1.1
SS-60	ND	ND	ND	ND	ND	ND	ND	ND	**3.0**
SS-61	ND	ND	ND	ND	ND	ND	ND	ND	1.9
SS-62	ND	ND	ND	ND	ND	ND	ND	ND	**2.4**
SS-63	ND	ND	ND	ND	ND	ND	ND	ND	0.45
SS-65	ND	ND	ND	ND	ND	ND	ND	ND	0.62
SS-66	-	-	-	-	-	-	-	-	-
SS-67	ND	ND	ND	ND	ND	ND	ND	0.010	0.12
SS-68	ND	ND	ND	ND	ND	ND	0.010	ND	0.43
SS-69/70	ND	ND	ND	ND	ND	ND	ND	ND	0.49
SS-71/72	ND	ND	ND	ND	0.26	ND	ND	ND	**14**
SS-73/74	ND	ND	ND	ND	0.20	0.002	ND	ND	**4.2**
SS-75	ND	ND	ND	ND	0.13	ND	0.027	ND	**2.0**
SS-78	ND	ND	ND	ND	ND	ND	ND	ND	0.82
SS-79/80	ND	ND	ND	ND	ND	ND	ND	ND	0.165
SS-81	ND	ND	ND	ND	ND	ND	ND	ND	0.72
SS-82	ND	ND	ND	ND	1.1	ND	ND	ND	**4.2**

bold = parameter level exceeds Primary or Secondary MCL ND = not detected above minimum reporting level
* = concentration exceeds the revised arsenic SDWA Primary MCL of 0.01 mg/L which becomes effective in 2006

Appendix B. Groundwater Quality Data, San Simon Sub-Basin--Continued

Site #	Iron (mg/L)	Lead (mg/L)	Manganese (mg/L)	Mercury (mg/L)	Nickel (mg/L)	Selenium (mg/L)	Silver (mg/L)	Thallium (mg/L)	Zinc (mg/L)
S-A	ND	ND	ND	ND	-	0.009	ND	ND	ND
S-B/C	ND	ND	ND	ND	-	ND	ND	ND	0.12
S-D	ND	ND	ND	ND	-	0.0062	ND	ND	ND
S-E	ND	ND	ND	ND	-	0.0064	ND	ND	0.52
S-F	ND	ND	ND	ND	-	ND	ND	ND	ND
S-G	ND	ND	ND	ND	-	ND	ND	ND	ND
S-H	ND	ND	ND	ND	-	ND	ND	ND	ND
S-I	ND	ND	ND	ND	-	0.012	ND	ND	0.055
S-J	ND	ND	ND	ND	-	ND	ND	ND	ND
S-K	**0.50**	ND	ND	ND	-	ND	ND	ND	0.69
S-L	ND	ND	ND	ND	-	ND	ND	ND	ND
S-M	ND	ND	ND	ND	-	ND	ND	ND	ND
S-N	ND	ND	ND	ND	-	ND	ND	ND	ND
S-O	ND	ND	ND	ND	-	ND	ND	ND	ND
S-P	ND	ND	ND	.00082	-	ND	ND	ND	0.43
SS-1	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-2	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-3/4	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-5	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-6/7	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-8	0.19	ND	ND	ND	ND	<0.025	ND	ND	0.44
SS-9	ND	ND	ND	ND	ND	ND	ND	ND	0.61
SS-10	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-11	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-12	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-13	ND	ND	ND	ND	ND	ND	ND	ND	0.059
SS-15	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-16	0.059	ND	ND	ND	ND	ND	ND	ND	ND

bold = parameter level exceeds Primary or Secondary MCL   ND = not detected above minimum reporting level

Appendix B. Groundwater Quality Data, San Simon Sub-Basin--Continued

Site #	Iron (mg/L)	Lead (mg/L)	Manganese (mg/L)	Mercury (mg/L)	Nickel (mg/L)	Selenium (mg/L)	Silver (mg/L)	Thallium (mg/L)	Zinc (mg/L)
SS-17	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-18	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-19/20	ND	ND	ND	ND	ND	ND	ND	ND	0.20
SS-21	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-22	0.068	ND	ND	ND	ND	ND	ND	ND	0.065
SS-23	ND	ND	ND	ND	ND	ND	ND	ND	0.16
SS-24	0.058	ND	ND	ND	ND	0.0061	ND	ND	ND
SS-25	ND	0.014	ND	ND	ND	ND	ND	ND	3.2
SS-26	0.20	ND	ND	ND	ND	ND	ND	ND	0.27
SS-27	**3.9**	ND	**0.058**	ND	ND	ND	ND	ND	0.085
SS-28	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-29/30	0.073	ND	ND	ND	ND	ND	ND	ND	0.25
SS-31a	ND	ND	ND	ND	ND	ND	ND	ND	0.13
SS-31/32	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-33	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-35	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-36	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-37	ND	ND	ND	ND	ND	ND	ND	ND	0.48
SS-38	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-39	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-40	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-41	ND	ND	ND	ND	ND	ND	ND	ND	0.084
SS-43/44	ND	ND	ND	ND	ND	ND	ND	ND	0.052
SS-45	0.25	ND	ND	ND	ND	ND	ND	ND	0.26
SS-46	ND	ND	ND	ND	ND	ND	ND	ND	0.69
SS-47	0.14	ND	ND	ND	ND	ND	ND	ND	0.14
SS-48	**0.38**	ND	ND	ND	ND	ND	ND	ND	ND
SS-49	ND	ND	ND	ND	ND	ND	ND	ND	0.093

bold = parameter level exceeds Primary or Secondary MCL ND = not detected above minimum reporting level

Appendix B. Groundwater Quality Data, San Simon Sub-Basin--Continued

Site #	Iron (mg/L)	Lead (mg/L)	Manganese (mg/L)	Mercury (mg/L)	Nickel (mg/L)	Selenium (mg/L)	Silver (mg/L)	Thallium (mg/L)	Zinc (mg/L)
SS-50	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-51	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-52	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-53/54	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-55	**4.6**	ND	**0.16**	ND	ND	ND	ND	ND	0.16
SS-56	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-57	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-58/59	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-60	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-61	ND	ND	ND	ND	ND	ND	ND	ND	0.058
SS-62	ND	ND	ND	ND	ND	ND	ND	ND	0.092
SS-63	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-65	ND	ND	ND	ND	ND	ND	ND	ND	0.27
SS-66	-	-	-	-	-	-	-	-	-
SS-67	**0.37**	ND	**0.074**	ND	ND	ND	ND	ND	0.15
SS-68	ND	ND	ND	ND	ND	ND	ND	ND	0.067
SS-69/70	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-71/72	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-73/74	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-75	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-78	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-79/80	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-81	ND	ND	ND	ND	ND	ND	ND	ND	ND
SS-82	ND	ND	ND	ND	ND	ND	ND	ND	ND

bold = parameter level exceeds Primary or Secondary MCL   ND = not detected above minimum reporting level

Appendix B. Groundwater Quality Data, San Simon Sub-Basin--Continued

Site #	Gross Alpha (pCi/L)	Gross Beta (pCi/L)	Ra-226 (pCi/L)	Ra-228 (pCi/L)	Uranium (ug/L)	δ^{18} O ($^0/_{00}$)	δ D ($^0/_{00}$)	Radon-222 (pCi/L)	Type of Chemistry
S-A	-	-	-	-	-	-	-	-	sodium-mixed
S-B/C	-	-	-	-	-	-	-	-	sodium-mixed
S-D	-	-	-	-	-	-	-	-	mixed-sulfate
S-E	-	-	-	-	-	-	-	-	mixed-sulfate
S-F	4.98	5.89	0.02	0.55	-	-	-	-	calcium-bicarbonate
S-G	5.20	2.54	0.02	1.35	-	-	-	-	sodium-bicarbonate
S-H	-	-	-	-	-	-	-	-	sodium-sulfate
S-I	-	-	-	-	-	-	-	-	sodium-sulfate
S-J	-	-	-	-	-	-	-	-	calcium-bicarbonate
S-K	5.01	2.67	0.00	0.21	-	-	-	-	calcium-mixed
S-L	-	-	-	-	-	-	-	-	sodium-sulfate
S-M	-	-	-	-	-	-	-	-	sodium-mixed
S-N	-	-	-	-	-	-	-	-	calcium-mixed
S-O	-	-	-	-	-	-	-	-	sodium-bicarbonate
S-P	1.35	1.45	0.00	1.01	-	-	-	-	calcium-bicarbonate
SS-1	-	-	-	-	-	- 11.1	- 81	831	sodium-mixed
SS-2	-	-	-	-	-	-	-	-	sodium-mixed
SS-3/4	-	-	-	-	-	-	-	-	sodium-mixed
SS-5	11	13	< LLD	-	-	- 9.2	- 67	657	sodium-mixed
SS-6/7	-	-	-	-	-	- 11.1	- 82	-	sodium-mixed
SS-8	-	-	-	-	-	- 11.1	- 80	-	sodium-mixed
SS-9	-	-	-	-	-	- 11.1	- 83	488	sodium-mixed
SS-10	< LLD	18	-	-	-	- 10.8	- 83	331	sodium-mixed
SS-11	-	-	-	-	-	- 10.1	- 84	-	sodium-mixed
SS-12	-	-	-	-	-	- 10.6	- 75	824	sodium-sulfate
SS-13	4.3	4.1	-	-	-	- 7.7	- 63	-	sodium-bicarbonate
SS-15	-	-	-	-	-	- 9.6	- 70	432	sodium-sulfate
SS-16	-	-	-	-	-	- 8.2	- 57	-	sodium-bicarbonate

bold = parameter level exceeds Primary or Secondary MCL ND = not detected above minimum reporting level LLD = Lower Limit of Detection

Appendix B. Groundwater Quality Data, San Simon Sub-Basin--Continued

Site #	Gross Alpha (pCi/L)	Gross Beta (pCi/L)	Ra-226 (pCi/L)	Ra-228 (pCi/L)	Uranium (ug/L)	δ D ($^0/_{00}$)	δ^{18} O ($^0/_{00}$)	Radon-222 (pCi/L)	Type of Chemistry
SS-17	-	-	-	-	-	- 9.9	- 71	-	sodium-bicarbonate
SS-18	-	-	-	-	-	- 11.4	- 82	-	sodium-mixed
SS-19/20	3.4	16	-	-	-	- 9.65	- 77	331	sodium-mixed
SS-21	-	-	-	-	-	- 11.5	- 78	-	sodium-bicarbonate
SS-22	-	-	-	-	-	- 12.0	- 82	304	sodium-bicarbonate
SS-23	2.1	2.0	-	-	-	- 9.5	- 68	-	sodium-bicarbonate
SS-24	-	-	-	-	-	- 10.1	- 73	-	sodium-bicarbonate
SS-25	7.9	3.3	< LLD	-	-	- 10.4	- 71	2893	mixed-bicarbonate
SS-26	-	-	-	-	-	- 12.3	- 89	-	sodium-bicarbonate
SS-27	-	-	-	-	-	- 10.4	- 73	-	mixed-bicarbonate
SS-28	-	-	-	-	-	- 10.7	- 73	4419	calcium-bicarbonate
SS-29/30	5.9	3.4	< LLD	-	-	- 11.0	- 75.5	-	sodium-bicarbonate
SS-31a	-	-	-	-	-	- 7.2	-53	-	sodium-mixed
SS-31/32	< LLD	3.1	-	-	-	- 9.9	- 66	141	calcium-sulfate
SS-33	-	-	-	-	-	- 10.1	- 63	-	calcium-bicarbonate
SS-35	-	-	-	-	-	- 10.4	- 68	641	calcium-bicarbonate
SS-36	-	-	-	-	-	-11.1	- 79	-	mixed-bicarbonate
SS-37	2.5	2.9	-	-	-	- 9.1	- 66	134	mixed-bicarbonate
SS-38	2.2	2.0	-	-	-	- 9.0	- 64	370	calcium-sulfate
SS-39	-	-	-	-	-	- 9.9	- 70	425	sodium-bicarbonate
SS-40	-	-	-	-	-	- 9.9	- 70	-	calcium-bicarbonate
SS-41	-	-	-	-	-	- 10.2	- 72	1189	calcium-bicarbonate
SS-43/44	-	-	-	-	-	- 9.75	- 68.5	729	mixed-bicarbonate
SS-45	-	-	-	-	-	- 9.8	- 71	-	calcium-bicarbonate
SS-46	6.6	2.1	< LLD	-	-	- 9.0	- 64	-	calcium-bicarbonate
SS-47	-	-	-	-	-	-10.9	- 80	673	sodium-bicarbonate
SS-48	**36**	9.5	< LLD	-	**34**	-11.5	- 83	1840	sodium-bicarbonate
SS-49	**20**	4.0	< LLD	-	18	- 8.9	- 62	74	sodium-mixed

bold = parameter level exceeds Primary or Secondary MCL   ND = not detected above minimum reporting level   LLD = Lower Limit of Detection

Appendix B. Groundwater Quality Data, San Simon Sub-Basin--Continued

Site #	Gross Alpha (pCi/L)	Gross Beta (pCi/L)	Ra-226 (pCi/L)	Ra-228 (pCi/L)	Uranium (ug/L)	δ D ($^{0}/_{00}$)	δ^{18} O ($^{0}/_{00}$)	Radon-222 (pCi/L)	Type of Chemistry
SS-50	**16**	5.0	< LLD	-	17	- 9.9	- 69	-	sodium-bicarbonate
SS-51	-	-	-	-	-	- 10.1	- 69	731	calcium-bicarbonate
SS-52	-	-	-	-	-	- 10.1	- 69	-	mixed-bicarbonate
SS-53/54	-	-	-	-	-	- 9.5	- 65.5	-	calcium-sulfate
SS-55	2.4	3.0	-	-	-	- 10.6	- 73	241	calcium-bicarbonate
SS-56	-	-	-	-	-	- 10.8	- 75	642	calcium-bicarbonate
SS-57	4.6	2.5	-	-	-	- 9.6	- 67	437	calcium-bicarbonate
SS-58/59	-	-	-	-	-	- 9.35	- 66	573	mixed-bicarbonate
SS-60	-	-	-	-	-	- 10.5	- 73	-	mixed-bicarbonate
SS-61	-	-	-	-	-	- 10.3	- 73	-	calcium-bicarbonate
SS-62	-	-	-	-	-	- 9.2	- 66	457	calcium-bicarbonate
SS-63	< LLD	2.3	-	-	-	- 10.5	- 72	-	sodium-bicarbonate
SS-65	-	-	-	-	-	- 9.8	- 67	1062	calcium-bicarbonate
SS-66	-	-	-	-	-	- 9.6	-67	-	-
SS-67	-	-	-	-	-	- 10.0	- 70	1754	calcium-bicarbonate
SS-68	-	-	-	-	-	- 9.1	- 64	179	calcium-bicarbonate
SS-69/70	-	-	-	-	-	- 9.8	- 71	-	sodium-mixed
SS-71/72	-	-	-	-	-	- 11.4	- 81	1294	sodium-bicarbonate
SS-73/74	-	-	-	-	-	- 9.2	- 66	533	sodium-sulfate
SS-75	-	-	-	-	-	- 8.6	- 67	375	mixed-bicarbonate
SS-78	6.0	-	-	-	-	- 9.7	- 68	-	calcium-bicarbonate
SS79/80	1.1	-	-	-	-	-10.0	- 69	33	mixed-mixed
SS-81	-	-	-	-	-	- 9.2	- 64	-	calcium-sulfate
SS-82	-	-	-	-	-	- 9.1	- 67	-	sodium-sulfate

bold = parameter level exceeds Primary or Secondary MCL   ND = not detected above minimum reporting level   LLD = Lower Limit of Detection

APPENDIX C. INVESTIGATION METHODS

Various groundwater sites were sampled by the ADEQ Groundwater Monitoring Program to characterize regional groundwater quality in the SS. Samples were collected at all sites for inorganic (physical parameters, major ions, nutrients, and trace elements). At selected sites samples were collected for hydrogen and oxygen isotope, radon, radiochemistry and pesticide analysis. No bacteria sampling was conducted because microbiological contamination problems in groundwater are often transient and subject to a variety of changing environmental conditions including soil moisture content and temperature.[17]

Sampling Strategy

This study focused on regional groundwater quality conditions that are large in scale and persistent in time. This research is designed to identify regional degradation of groundwater quality such as occurs from non-point sources of pollution or a high density of point sources. The quantitative estimation of regional groundwater quality conditions requires the selection of sampling locations that follow scientific principles for probability sampling.[19]

Sampling in the SS conducted by ADEQ followed a systematic stratified random site-selection approach. This is an efficient method because it requires sampling relatively few sites to make valid statistical statements about the conditions of large areas. This systematic element requires that the selected wells be spatially distributed while the random element ensures that every well within a cell has an equal chance of being sampled. This strategy also reduces the possibility of biased well selection and assures adequate spatial coverage throughout the study area.[19] The main benefit of a statistically-designed sampling plan is that it allows for greater groundwater quality assumptions than would be allowable with a non-statistical approach.

Wells pumping groundwater for a variety of purposes - domestic, stock, and industrial - were sampled for this study, provided each individual well met ADEQ requirements. A well was considered suitable for sampling if the well owner gave permission to sample, if a sampling point existed near the wellhead, and if the well casing and surface seal appeared to be intact and undamaged.[5] Other factors such as casing access to determine groundwater depth and construction information were preferred but not essential.

If registered wells were unavailable for sampling, springs or unregistered wells were randomly selected for sampling. Springs were considered adequate for sampling if they had a constant flow through a clearly-defined point of egress, and if the sample point had minimal surface impacts. Well information compiled from the ADWR well registry and spring data are found in Appendix A.

Several factors were considered to determine sample size for this study. Aside from administrative limitations on funding and personnel, this decision was based on three factors related to the conditions in the area:

- Amount of groundwater quality data already available;
- Extent to which impacted groundwater is known or believed likely to occur; and
- Geologic and hydrologic complexity and variability of the basin.[19]

Sample Collection

The personnel who designed the SS study were also responsible for the collection and interpretation of the data. This protocol helps ensure that consistently high quality data are collected, from which are drawn relevant and meaningful interpretations. The sample collection methods for this study conformed to the Quality Assurance Project Plan (QAPP)[1] and the Field Manual For Water Quality Sampling.[5] These sources should be consulted as references to specific sampling questions; however, a brief synopsis of the procedures in collecting a groundwater sample is provided.

After obtaining permission from the owner to sample the well, the water level was measured with a sounder if the casing had access for a probe. The volume of water needed to purge the well three bore-hole volumes was calculated from well log and on-site information. Physical parameters - temperature, pH, and specific conductivity - were monitored at least every five minutes using a YSI multi-parameter instrument. To assure obtaining fresh water from the aquifer, typically after three bore volumes had been pumped and the physical parameters were stabilized within 10 percent, a sample representative of the aquifer was collected from a point as close to the wellhead as possible. In certain instances, it was not possible to purge three bore volumes. In these cases, at least one bore volume was evacuated and the physical parameters had stabilized within 10 percent.

Sample bottles were filled in the following order:

1. Pesticide
2. Radon
3. Inorganic
4. Radiochemistry
5. Isotope

Radon samples were collected in two unpreserved, 40-ml clear glass vials. Radon samples were carefully filled and sealed so that no headspace remained.[16]

The inorganic constituents were collected in three, 1-liter polyethylene bottles:

- Samples to be analyzed for dissolved metals were filtered into bottles and preserved with 5 ml nitric acid (70 percent). An on-site positive pressure filtering apparatus with a 0.45 micron (µm) pore size groundwater capsule filter was used.

- Samples to be analyzed for nutrients were collected in bottles and preserved with 2 ml sulfuric acid (95.5 percent).

- Samples to be analyzed for other parameters were unpreserved.[27]

Radiochemistry samples were collected in two collapsible 1-liter plastic containers and preserved with 5 ml nitric acid to reduce the pH below 2.5 su.[5]

Hydrogen and oxygen isotope samples were collected in a single 500 ml plastic bottle and were not preserved.

Samples were kept at 4^0C with ice in an insulated cooler, with the exception of the isotope and radiochemistry samples. Chain of custody procedures were followed in sample handling. Samples for this study were collected in June 1997, May 2001, and May - September 2002.

Laboratory Methods

The inorganic analyses for this study were conducted by the Arizona Department of Health Services (ADHS) Laboratory in Phoenix, Arizona, with inorganic splits analyzed by Del Mar Laboratory in Phoenix, Arizona. A complete listing of inorganic parameters, including laboratory method, EPA water method, and Minimum Reporting Level (MRL) for both laboratories is provided in Table 13.

The radon and radiochemistry samples were analyzed by Radiation Safety Engineering, Inc. Laboratory in Chandler, AZ. The analysis of radiochemistry samples was performed according to the following SDW protocols: Gross alpha was analyzed, and if levels exceeded 5 pCi/L, then radium-226 was measured. If radium-226 exceeded 3 pCi/L, radium-228 was measured. If gross alpha levels exceeded 15 pCi/L initially, then radium-226/228 and total uranium were measured.

Hydrogen and oxygen isotope samples were analyzed by the University of Arizona, Laboratory of Isotope Geochemistry in Tucson.

Sample Numbers

Seventy-seven (77) groundwater sites (plus one surface water site) were sampled for the study. Various numbers and types of samples were collected and analyzed:

- 77 - inorganic
- 62 - hydrogen and oxygen isotopes
- 33 - radon
- 23 - radiochemistry
- 4 - pesticide.

Table 13. ADHS/Del Mar Laboratory Methods Used for the SS Study

Constituent	Instrumentation	ADHS / Del Mar Water Method	ADHS / Del Mar Minimum Reporting Level
Physical Parameters and General Mineral Characteristics			
Alkalinity	Electrometric Titration	SM232OB	2 / 5
SC (µS/cm)	Electrometric	EPA 120.1/ SM2510B	1 / 2
Hardness	Titrimetric, EDTA	EPA 130.2 / SM2340B	10 / 1
Hardness - Calc.	Calculation	--	--
pH (su)	Electrometric	EPA 150.1	0.1
TDS	Gravimetric	EPA 160.1 / SM2540C	10 / 20
Turbidity (NTU)	Nephelometric	EPA 180.1	0.01 / 1
Major Ions			
Calcium	ICP-AES	EPA 200.7	5 / 2
Magnesium	ICP-AES	EPA 200.7	1 / 0.5
Sodium	ICP-AES	EPA 200.7 / EPA 273.1	5
Potassium	Flame AA	EPA 258.1	0.5 / 1
Bicarbonate	Calculation	--	2
Carbonate	Calculation	--	2
Chloride	Potentiometric Titration	SM 4500 CLD / EPA 300.0	1 / 5
Sulfate	Colorimetric	EPA 375.2 / EPA 300.0	10 / 5
Nutrients			
Nitrate as N	Colorimetric	EPA 353.2	0.02 / 0.50
Nitrite as N	Colorimetric	EPA 353.2	0.02
Ammonia	Colorimetric	EPA 350.1/ EPA 350.3	0.02 / 0.5
TKN	Colorimetric	EPA 351.2 / SM4500	0.05 / 0.5
Total Phosphorus	Colorimetric	EPA 365.4 / EPA 365.3	0.02 / 0.05

All units are mg/L except as noted
Source [16 27]

Table 13. ADHS/Del Mar Laboratory Methods Used for the SS Study--Continued

Constituent	Instrumentation	ADHS / Del Mar Water Method	ADHS / Del Mar Minimum Reporting Level
		Trace Elements	
Antimony	Graphite Furnace AA	EPA 200.9	0.005 / 0.004
Arsenic	Graphite Furnace AA	EPA 200.9	0.01 / 0.003
Barium	ICP-AES	EPA 200.7	0.1 / 0.01
Beryllium	Graphite Furnace AA	EPA 200.9	0.0005
Boron	ICP-AES	EPA 200.7	0.1 / 0.5
Cadmium	Graphite Furnace AA	EPA 200.9	0.001 / 0.0005
Chromium	Graphite Furnace AA	EPA 200.9	0.01 / 0.004
Copper	Graphite Furnace AA	EPA 200.9	0.01 / 0.004
Fluoride	Ion Selective Electrode	SM 4500 F-C	0.2 / 0.1
Iron	ICP-AES	EPA 200.7	0.1
Lead	Graphite Furnace AA	EPA 200.9	0.005 / 0.002
Manganese	ICP-AES	EPA 200.7	0.05 / 0.02
Mercury	Cold Vapor AA	SM 3112 B / EPA 245.1	0.0005 / 0.0002
Nickel	ICP-AES	EPA 200.7	0.1 / 0.05
Selenium	Graphite Furnace AA	EPA 200.9	0.005 / 0.004
Silver	Graphite Furnace AA	EPA 200.9 / EPA 273.1	0.001 / 0.005
Thallium	Graphite Furnace AA	EPA 200.9	0.002
Zinc	ICP-AES	EPA 200.7	0.05

All units are mg/L
Source [16 27]

APPENDIX D. DATA EVALUATION

Quality Assurance

Quality-assurance (QA) procedures were followed and quality-control (QC) samples were collected to quantify data bias and variability for the SS study. The design of the QA/QC plan was based on recommendations included in the *Quality Assurance Project Plan* (*QAPP*)[1] and *the Field Manual For Water Quality Sampling*.[5] The types and numbers of QC samples collected for this study are as follows:

Inorganic: (5 full duplicate, 2 partial filter duplicates,
5 splits, 5 full blanks, 1 partial filter blanks).
Isotope: (5 duplicates, 0 splits, 0 blanks).
Radiochemical: (0 duplicates, 0 splits, 0 blanks).
Radon: (0 duplicates, 0 splits, 0 blanks).
Pesticide: (0 duplicates, 0 splits, 0 blanks).

Based on the QA/QC results, sampling procedures and laboratory equipment did not significantly affect the groundwater quality samples of this study.

Blanks - Equipment blanks for inorganic analyses were collected to ensure adequate decontamination of sampling equipment, and that the filter apparatus and/or de-ionized water were not impacting the groundwater quality sampling.[5] Equipment blank samples for major ion and nutrient analyses were collected by filling unpreserved and sulfuric acid preserved bottles with de-ionized water. Equipment blank samples for trace element analyses were collected with de-ionized water that had been filtered into nitric acid preserved bottles.

Systematic contamination was judged to occur if more than 50 percent of the equipment blank samples contained measurable quantities of a particular groundwater quality constituent.[10] As such, SC-lab and turbidity were considered to be affected by systematic contamination; however, the extent of contamination was not considered significant. SC was detected in all five full equipment blanks while turbidity was detected in four full equipment blanks. SC had a mean of 1.8 µS/cm, which was less than 1 percent of the SC mean level for the study. The SC detections may be explained in two ways: water passed through a de-ionizing exchange unit will normally have an SC value of at least 1 µS/cm, and carbon dioxide from the air can dissolve in de-ionized water with the resulting bicarbonate and hydrogen ions imparting the observed conductivity.[27] Similarly, turbidity had a mean level of 0.035 ntu, less than 1 percent of the turbidity median level for the study. Testing indicates turbidity is present at 0.01 ntu in the de-ionized water supplied by the ADHS laboratory, and levels increase with time due to storage in ADEQ carboys.[27]

Three other constituents were detected in the blanks but none appeared to significantly impact sampling results. Copper was detected at 0.011 mg/l in SS-14 but no other samples collected during that field trip had detections of this constituent. Mercury was detected at 0.00095 mg/l in SS-34 but again no other samples collected during that field trip had detections of this constituent. The ADHS lab personnel thought that the nitric acid preservative bottle may have been contaminated as no mercury was detected in the unpreserved sample.[27] Chloride was also detected in SS-14 at 5 mg/l.

Duplicate Samples - Duplicate samples are identical sets of samples collected from the same source at the same time and submitted to the same laboratory. Data from duplicate samples provide a measure of variability from the combined effects of field and laboratory procedures.[5] Duplicate samples were collected from sampling sites that were believed to have elevated constituent concentrations as judged by field SC values. Partial filter duplicate samples were also collected in two cases. These occurred by collecting an extra duplicate sample in an unpreserved container. Upon submission to the ADHS laboratory, this sample water would be filtered and preserved with nitric acid.

Variability in constituent concentrations between each pair of duplicate samples is provided both in terms of absolute levels and as the percent difference. Percent difference is defined as the absolute difference between levels in the duplicate samples divided by the average level for the duplicate samples, multiplied by 100. Only constituents having levels exceeding the Minimum Reporting Level (MRL) were used in this analysis. Most constituents were examined using four duplicate samples, cations and trace elements were examined using an extra two duplicate filter samples.

Analytical results indicate that of the 37 constituents examined, only 20 constituents had concentrations above MRLs in which both duplicate samples (Table 14). Cadmium and nitrate were detected near the MRL in one sample, the other sample reporting a non-detect. With total phosphorus, this pattern occurred with two sets of duplicate samples.

Table 14. Summary Results of SS Duplicate Samples from ADHS Laboratory

Parameter	Number	Difference in Percent			Difference in Concentrations		
		Minimum	Maximum	Median	Minimum	Maximum	Median
Physical Parameters and General Mineral Characteristics							
Alkalinity, Total	5	0 %	2 %	0 %	0	10	0
SC (µS/cm)	5	0 %	4 %	0 %	0	100	0
Hardness	5	0 %	3%	0 %	0	10	0
pH-field (su)	5	0 %	2 %	0 %	0	0.3	0
TDS	5	0 %	3 %	0 %	0	10	0
Turbidity (NTU)	4	5 %	67 %	17 %	0.02	0.1	0.07
Major Ions							
Bicarbonate	5	0 %	2 %	1 %	0	10	3
Carbonate	5	0 %	0 %	0 %	0	0	0
Calcium	7	0 %	4 %	2 %	0	10	0.15
Magnesium	7	0 %	6 %	0 %	0	0.9	0
Sodium	7	0 %	7 %	1 %	0	20	5
Potassium	7	0 %	8 %	0 %	0	1.3	0
Chloride	5	0 %	40 %	0 %	0	10	0
Sulfate	5	0 %	1 %	0 %	0	10	0
Nutrients							
Nitrate (as N)	5	0 %	0 %	0 %	0	0.02	0
TKN	5	0 %	3 %	0 %	0	0.003	0
Trace Elements							
Arsenic	7	0 %	8 %	0 %	0	0.011	0
Boron	7	0 %	2 %	0 %	0	0.02	0
Fluoride	5	0 %	3 %	0 %	0	0.06	0
Zinc	7	0 %	32 %	0%	0	0.078	0

All units are mg/L except as noted with certain physical parameters
Note: In one duplicate, cadmium and nitrate were detected at near the MRL in one sample and not detected in the other sample. In two duplicates, total phosphorus was detected near the MRL in two samples and not detected in the other two samples.

The maximum difference between duplicate constituents never exceeded 8 percent with the exception of zinc (32 percent), chloride (40 percent), and turbidity (67 percent). Turbidity values can be impacted by the exceedance of this parameter's holding time[27]; this occurred frequently during the study. Although chloride had a high percentage difference, it had a relatively small concentration difference (3.6 mg/L). Based on these results, the differences in constituent concentrations of duplicate samples were not considered to significantly impact the groundwater quality data.

Split Samples - Split samples are identical sets of samples collected from the same source at the same time that are submitted to two different laboratories to check for laboratory differences.[5] Five inorganic split samples were collected. Analytical results from the split samples were evaluated by examining the variability in constituent concentrations in terms of absolute levels and as the percent difference.

Analytical results indicate that of the 38 constituents examined, only 19 had concentrations above MRLs for both ADHS and Del Mar laboratories in at least one sample. The maximum difference between split constituents rarely exceeded 20 percent (Table 15). As usual, TKN exhibited the largest maximum difference (100%), a pattern which has been found in other ADEQ ambient groundwater studies and is due to the difficulty in analyzing this constituent.[16 27] In three splits, TKN was detected in the Del Mar laboratory sample but not in the ADHS sample; in one split the pattern was reversed.

Split samples were also evaluated using the non-parametric Sign test to determine if there were any significant ($p \leq 0.05$) differences between ADHS laboratory and Del Mar Laboratory analytical results.[10] Results of the Sign test showed that none of the 19 constituents examined had significantly different concentrations between the laboratories.

ADEQ 1997-2002 Well Comparison - As an additional QA/QC measurement, two wells that were sampled as part of the 1997 ADEQ Upper Gila Watershed study were resampled in 2002.[37] The two wells resampled include a deep artesian well (BLM Hot Springs Well) and a windmill (Antelope Well).

Analytical results indicate that of the 18 constituents examined, the maximum difference between sample constituents typically did not exceed 15 percent (Table 16). When there were large maximum percentage differences, there were relatively small concentration differences. Near the MRL, the error can be large as the result of small concentration differences. Constituents with large maximum percentage differences included those having difficult analytical methods (turbidity and TKN) as well as with nitrate and arsenic.

These results appear to indicate that data collected by ADEQ in 1997 and 2002 can be used interchangably in the current assessment of San Simon sub-basin groundwater quality.

Also based on the results of blanks, duplicates, and split samples, there appeared to be no significant QA/QC problems with the groundwater quality collected for this study.

Data Validation

The analytical work for this study was subjected to the following six QA/QC correlations.

Cation/Anion Balances - In theory, water samples exhibit electrical neutrality. Therefore, the sum of milliequivalents per liter (meq/L) of cations must equal the sum of meq/L of anions. However, this neutrality rarely occurs due to unavoidable variation inherent in all water quality analyses. Still, if the cation/anion balance is found to be within acceptable limits, it can be assumed there are no gross errors in concentrations reported for major ions.[20]

Overall, cation/anion balances of SS samples were significantly correlated (regression analysis, $p \leq 0.01$) and were within acceptable limits (90 - 110 percent).

SC/TDS - The SC and TDS concentrations measured by contract laboratories were significantly correlated as were field-SC and TDS concentrations (regression analysis, $p \leq 0.01$). Typically, the TDS concentration in mg/L should be from 0.55 to 0.75 times the SC in µS/cm for groundwater up to several thousand mg/L.[20] Groundwater in which the ions are mostly bicarbonate and chloride will have a multiplication factor near the lower end of this range and groundwater high in sulfate may reach or even exceed the higher number. The relationship of TDS to SC becomes undefined for groundwater either with very high and low concentrations of dissolved solids.[20]

Table 15. Summary Results of SS Split Samples From ADHS/Del Mar Labs

Constituents	Number	Difference in Percent		Difference in Levels		Significance
		Minimum	Maximum	Minimum	Maximum	
Physical Parameters and General Mineral Characteristics						
Alkalinity, total	5	0 %	4 %	0	10	ns
Alk., phenol	5	0 %	39 %	0	7.9	ns
SC (µS/cm)	5	0 %	6 %	0	40	ns
Hardness	5	0 %	14 %	0	20	ns
pH (su)	5	1 %	4 %	0.09	0.58	ns
TDS	5	0 %	8 %	0	10	ns
Turbidity (NTU)	5	0 %	19 %	0	1.3	ns
Major Ions						
Calcium	5	0 %	2 %	0	1	ns
Magnesium	5	0 %	3 %	0	2	ns
Sodium	5	0 %	5 %	0	10	ns
Potassium	5	1 %	4 %	0.1	0.2	ns
Chloride	5	0 %	12 %	0	11	ns
Sulfate	5	1 %	5 %	0.7	10	ns
Nutrients						
Nitrate as N	5	0 %	7 %	0	0.2	ns
TKN	5	0 %	100 %	0	2.5	ns
Trace Elements						
Arsenic	5	0 %	3 %	0	0.001	ns
Boron	5	0 %	0 %	0	0	ns
Fluoride	4	0 %	9 %	0	0.1	ns
Zinc	5	0 %	100 %	0	0.52	ns

All units are mg/L except as noted with certain physical parameters
ns = No significant ($p \leq 0.05$) difference between labs

Table 16. Summary Results of 1997/2002 ADEQ Well Sampling Comparison

Constituents	Number	Difference in Percent		Difference in Levels		Significance
		Minimum	Maximum	Minimum	Maximum	
Physical Parameters and General Mineral Characteristics						
Alkalinity, total	2	0 %	0 %	0	0	ns
Hardness	2	10 %	14 %	4	16.5	ns
pH-field (su)	2	1 %	2 %	0.1	0.15	ns
SC (µS/cm)	2	5 %	7 %	200	235	ns
TDS	2	1 %	4 %	10	100	ns
Turbidity (NTU)	1	58 %	58 %	2.93	2.93	ns
Major Ions						
Calcium	2	10 %	12 %	1.5	5	ns
Magnesium	2	0 %	17 %	0	0.45	ns
Sodium	2	0 %	1 %	0	5	ns
Potassium	2	6 %	13 %	0.65	0.9	ns
Bicarbonate	1	0 %	0 %	0	0	ns
Chloride	2	0 %	14 %	0	50	ns
Sulfate	2	1 %	3 %	5	20	ns
Nutrients						
Nitrate as N	2	0 %	76 %	0	0.356	ns
TKN	2	0 %	28 %	0	0.11	ns
Trace Elements						
Arsenic	2	12 %	25 %	0.009	0.021	ns
Boron	2	1 %	3 %	0.01	0.03	ns
Fluoride	2	2 %	5 %	0.35	1	ns

All units are mg/L except as noted with certain physical parameters
ns = No significant ($p \leq 0.05$) difference between labs
Note: Zinc was detected at the 1997 sample collected from Antelope Well at 0.12 mg/L and not detected above the MRL of 0.05 mg/L in 2002.[37]

Hardness - Concentrations of laboratory-measured and calculated values were significantly correlated (regression analysis, $p \leq 0.01$). Hardness concentrations were calculated using the following formula: [(Calcium x 2.497) + (Magnesium x 4.118)].

SC - The SC measured in the field using a YSI meter at the time of sampling was significantly correlated with the SC measured by contract laboratories (regression analysis, $p \leq 0.01$).

pH - The pH value is closely related to the environment of the water and is likely to be altered by sampling and storage.[20] Still, the pH values measured in the field using a YSI meter at the time of sampling were significantly correlated with laboratory pH values (regression analysis, $p \leq 0.01$).

Groundwater Temperature/Groundwater Depth - Groundwater temperature measured in the field was compared to groundwater depth to examine the relationship that exists between temperature and depth. Groundwater temperature should increase with depth, approximately 3 degrees Celsius with every 100 meters or 328 feet.[7] Groundwater temperature and water depth were however not significantly correlated (regression analysis, $p \leq 0.05$).

The analytical work conducted for this study was considered valid based on the quality control samples and the QA/QC correlations.

Statistical Considerations

Various methods were used to complete the statistical analyses for the groundwater quality data of this study. All statistical tests were conducted on a personal computer using SYSTAT software.[40]

Data Normality: Initially, data associated with 22 constituents were tested for both non-transformed and log-transformed normality using the Kolmogorov-Smirnov one-sample test with the Lilliefors option.[8] Results of this test using non-transformed data revealed that three constituents (pH-field, pH-lab, and oxygen-18) were normally distributed. This is not unusual as the distribution of many groundwater quality parameters is often not Gaussian or normal, but skewed to the right.[19] The results of the log-transformed test revealed that 14 of the 20 log-transformed constituents (isotopes being negative numbers were not able to be log-transformed) were normally-distributed with only temperature, turbidity, bicarbonate, sulfate, nitrate, gross beta, and deuterium not normally distributed. However, turbidity, sulfate, gross beta, and deuterium came close to being normally distributed. In summary, 14 percent of non-transformed data were normally-distributed while 70 percent of the log-transformed constituents were normally-distributed.

Spatial Relationships: The parametric analysis of variance (ANOVA) test was applied to investigate the hypothesis that constituent concentrations from groundwater sites in different aquifers or rock types, of the SS were the same. The ANOVA tests the equality of two or more means in experiments involving one continuous dependent variable and one categorical independent variable.[40] The null hypothesis of identical mean values for all data sets within each test was rejected if the probability of obtaining identical means by chance was less than or equal to 0.05. Comparisons conducted using the ANOVA test include aquifers (*alluvial*, *lower, upper*, and *bedrock*), water-bearing units (*alluvial*, *lower, upper*, Chiricahua, Dos Cabezas, Peloncillo, and Pinaleno) and rock types (alluvium, granite rock, volcanic rock, and basaltic rock).[26]

If the null hypothesis was rejected for any of the tests conducted, the Tukey method of multiple comparisons on the ranks of the data was applied. The Tukey test identified significant differences between constituent concentrations when compared to each possibility within each of the four tests.[19]

The ANOVA and Tukey tests are not valid for data sets with greater than 50 percent of the constituent concentrations below the MRL.[19] Consequently, they were not calculated for trace parameters such as antimony, barium, beryllium, cadmium, chromium, copper, lead, manganese, mercury, nickel, selenium, silver, thallium, phenolphthalein alkalinity, carbonate, nitrite, and ammonia. Constituents such as arsenic, iron, total phosphorus, total kjeldahl nitrogen (TKN), and zinc, although not having greater than 50 percent above the MRL, were calculated though the results should not be considered statistically-valid. Highlights of these statistical tests are summarized in the groundwater quality section.

Constituent Concentration Correlations: In order to assess the strength of association between constituents, their concentrations were compared to each other using the Pearson Correlation Coefficient test.

The Pearson correlation coefficient varies between -1 and +1, with a value of +1 indicating that a variable can be predicted perfectly by a positive linear function of the other, and vice versa. A value of -1 indicates a perfect inverse or negative relationship. The results of the Pearson Correlation Coefficient test were then subjected to a probability test to determine which of the individual pair wise correlations were significant.[40] The Pearson test is not valid for data sets with greater than 50 percent of the constituent concentrations below the MRL.[19] Consequently, Pearson Correlation Coefficients were not calculated for the same constituents as in spatial relationships. However, constituents such as arsenic, iron, total phosphorus, total kjeldahl nitrogen (TKN), and zinc, although not having greater than 50 percent above the MRL, were calculated though the results should not be considered statistically-valid.